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SARCOMA OF ESOPHAGUS: SURGICAL TREATMENT

John Borrie, Ch.M., F.R.C.S., Dunedin, New Zealand

INTRODUCTION

ALTHOUGH sarcomas of the esophagus are rare, the present-day wider appreciation that dysphagia means mechanical foregut obstruction which can usually be relieved and often cured by operation ensures that patients suffering from sarcoma of the esophagus will, from time to time, present themselves for treatment. What sarcomas of the esophagus treated surgically have been reported, and what are the results of such treatment?

The purpose of this paper is briefly to review published reports of surgical treatment of this lesion, to describe one further patient who, in 1952, was found to have a polypoid fibrosarcoma in the lower third of the esophagus one year after successful hiatal herniorrhaphy, and to report his continued good health 6 years after partial esophagogastrectomy (Table I).

PATHOLOGY

The first case of sarcoma of the esophagus was reported by Chapman[1] in 1877. The pathologic types and clinical features have been fully described in the past, especially by Dvorak,[2] who reviewed reported cases up to 1931, and ably discussed these particular aspects of the subject. Thorek and Neiman,[3] in 1950, collected 58 proved cases of sarcoma of the esophagus, which included 30 fibrosarcomas, 8 leiomyosarcomas, 5 lymphosarcomas, 5 melanosarcomas, 3 rhabdomyosarcomas, and 7 unclassified sarcomas. According to Ewing,[4] the age incidence varies from 4 to 70 years. These tumors are most commonly found in the lower third of the esophagus, and may vary greatly in size.

From the Department of Surgery, University of Otago, and Thoracic Surgical Department, Dunedin and Wakari Hospitals, New Zealand.
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Ewing describes two general types of growth, namely the *polypoid* and *ulcerative* forms. The former arise from the submucosa, are slow growing, they form a polypoid mass within the lumen of the esophagus, cause little tissue destruction, and they metastasize late. The latter grow rapidly, infiltrate widely, and ulcerate, with hemorrhage, focal necrosis, and even perforation.

CLINICAL FEATURES

These may advance more rapidly than with carcinoma of the esophagus. The commonest symptom is dysphagia, and is early associated with pain, which may be nocturnal and not associated with food. Weight loss accompanies the dysphagia, and Thorek and Neiman stress that when the degree of wasting is out of proportion to the degree of dysphagia, a sarcoma should be suspected rather than carcinoma. Further, they claim that sarcoma of the esophagus is more rapidly fatal than carcinoma, the patient rarely living more than 6 months after the onset of dysphagia. Although study of the cases in which there was surgical treatment does not confirm this, nevertheless long-term survival after successful surgical removal must remain closely related to early diagnosis and early appreciation of the significance of symptoms. Diagnosis is confirmed by esophagrams and esophagoscopy to secure a biopsy for histologic proof.

TREATMENT

Carcoma of the esophagus was invariably fatal until Harrington[5] first successfully resected one such growth in 1945. His patient was a woman, aged 60 years, who had increasing dysphagia for a year. Roentgenograms and esophagoscopy revealed an ulcerating polypoid lesion partially obstructing the lower third of the esophagus. A biopsy suggested sarcoma. On June 16, 1945, through a left transthoracic transdiaphragmatic incision, the lower half of the esophagus and cardiac end of the stomach were resected with esophagogastric anastomosis. She was discharged symptom-free 6 weeks after operation. The growth was a leiomyosarcoma. The patient was reported alive and well 7 years later.[6] Another patient described in the same paper, also a woman of 60 years, with a polypoid tumor involving the lower third of the esophagus and cardiac end of the stomach, was found to be inoperable owing to infiltration of the pulmonary vessels, left main bronchus, aorta, and pericardium.

Sweet's[7] patient, with a 4-month history, had a rhabdomyosarcoma resected in July, 1945, when a supra-aortic esophagogastric anastomosis was performed. The patient was an emphysematous, malnourished, arteriosclerotic woman of 78 years who died from pulmonary infection and cardiac failure on the twentieth postoperative day. No metastases were found either at operation or at autopsy.

Lyons and Garlock[8] had a success on April 10, 1946. The patient, 58-year-old woman, had suffered from progressive dysphagia for a year. Roentgenograms showed a large, well-circumscribed tumor involving the middle and lower thirds of the esophagus and projecting into its lumen. Esophagoscopy revealed, at 27 cm., a globular friable mass which biopsy proved to be a leiomyosarcoma.

Through a left transthoracic transdiaphragmatic approach, the growth was resected and an infra-aortic esophagogastric anastomosis performed. The polypoid tumor measured 10 cm. by 4 cm., and had a 5 mm. pedicle. Garlock later reported that while mobilizing this sausage-shaped pedunculated tumor, it disappeared downward into the stomach where it was found near the pylorus. The temptation to remove it locally via a gastrostomy incision was resisted, and wisely so, for subsequent pathologic study revealed that the growth infiltrated the muscular layer of the esophagus in the region of its pedicle, and could only have been adequately removed by formal esophagogastrectomy. It is interesting to note that at the gastroesophageal junction were three nodules, 3 mm. in diameter, which proved to be benign leiomyomas. The patient was well 7 years later.[9]

Clark's[10] patient, a man aged 43 years, was admitted to hospital on Feb. 22, 1947, had an 8-month history of dysphagia, with a 30 pound (13.6 Kg.) weight loss. Esophagrams revealed a large polypoid mass in the upper esophagus, and esophagoscopy confirmed that, at 26 cm. from the upper incisor teeth, there was an irregular grayish-brown firm mass. Biopsy revealed a fibrosarcoma. Through a left thoracotomy, he had an esophagectomy from the cardia to the base of the neck where an anastomosis between the fundus of the stomach and the esophagus was completed. The tumor was 12 cm. long and 4 cm. wide. The patient was well and working one month after operation.

Lortat-Jacob's[11] initial patient, aged 67 years, complaining of dysphagia for 2 months, had a fibrosarcoma 27 cm. from the incisor teeth. Through a left thoracotomy on April 4, 1947, the growth was resected by partial esophagectomy and esophagogastrostomy. He died from a transfusion reaction 3 days later.

On Jan. 3, 1948, his second patient, a man aged 53 years, with a 6-month history of dysphagia due to a growth at the cardia, had partial esophagectomy and an esophagogastric anastomosis. The growth was likewise a fibrosarcoma. This patient died 6 months after operation.

The patient of Brea and associates,[12] admitted to hospital on April 23, 1948, gave a history of progressive dysphagia and 10 Kg. weight loss in 10 months. Esophagrams showed a deformity and displacement at the lower end of the esophagus, and esophagoscopy confirmed narrowing from external compression. Following left thoracotomy, the lesion was found to lie in the lower esophageal wall as a well-circumscribed extramucosal tumor, and was enucleated through a muscle splitting incision. Histologically, it was a fibrosarcoma. Two and a half years later the growth recurred, it proved resistant to radiotherapy and the patient died.

Thorek and Neiman's[3] case was a male aged 43 years, with a 3-month history of dysphagia and an 11 pound weight loss in 8 weeks. Esophagrams showed a filling defect just below the aortic arch, and esophagoscopy a neoplastic lesion 27 cm. from the lower alveolar margin. Biopsy examination suggested a squamous-cell carcinoma. Supra-aortic esophagogastrectomy was performed on Aug. 4, 1948, when a tumor measuring 3.5 by 2.5 by 2.0 cm. was removed. Histopathology revealed a rhabdomyosarcoma of the esophagus.

TABLE I. SARCOMA OF ESOPHAGUS PATIENTS TREATED BY RESECTION

NO.	REPORT	AGE	SEX	DURATION OF SYMPTOMS	DATE OF OPERATION	DATE OF PAPER	TYPE OF LESION	SITE	TYPE OF OPERATION	RESULTS
1.	Harrington	60	F	1 yr.	6/16/45	1949	Leiomyosarcoma; nodular & diffuse	Lower third; ulcerative	L. partial esophagectomy; infra-aortic esophagogastrostomy	Well 7 yr. later
2.	Sweet et al.	78	F	4 mo.	July, 1945	1954	Rhabdomyosarcoma; nodular & diffuse	Mid third	L. partial esophagectomy; supra-aortic esophagogastric anastomosis	Died from pulmonary infection & heart failure, 20th day
3.	Lyons and Garlock	58	F	1 yr.	4/10/46	1951	Leiomyosarcoma	Lower third; polypoid	L. partial esophagectomy; infra-aortic esophagogastrostomy	Reported well 7 yr. later
4.	Clark	43	M	8 mo.	Not stated; adm. 2/22/47	1949	Fibrosarcoma	Middle and upper thirds; polypoid	L. partial esophagectomy; supra-aortic esophagogastrostomy	Working 1 mo. after operation
5.	Lortat-Jacob	67	M	2 mo.	4/ 4/47	1950	Fibrosarcoma	27 cm. from incisor teeth	L. thoracotomy; partial esophagectomy & esophagogastrostomy	Died 3 days postop., transfusion
6.	Lortat-Jacob	53	M	6 mo.	1/ 3/48	1950	Fibrosarcoma	Lower third	L. partial esophagectomy & esophagogastrostomy	Died 6 mo. after operation
7.	Brea et al.	65	M	10 mo.	4/23/48	1950	Fibrosarcoma; submucosal, no metastases	Lower esophagus	Enucleation	Recurred 2½ years later
8.	Thorek and Neiman	43	M	3 mo.	8/ 4/48	1950	Rhabdomyosarcoma	Middle third; polypoid	Partial-esophagectomy; supra-aortic esophagogastrostomy	Well a year after operation
9.	Maŭro and de Escobar	62	M	1 yr.	8/ 8/48	1951	"Sarcoma polymorphocellular"	Middle third; fungating	Torek type of resection	Died 11th postop. day
10.	Biasini	49	F	1 yr.	11/ 6/48	1949	Fibroleiomyosarcoma	Lower third	Esophagogastrostomy	Satisfactory

11.	Gaspar and Boado	46	M	6 mo.	4/ 4/49	1953	Leiomyosarcoma	28 cm. from lower incisors	Supra-umbilical laparotomy, dilatation of cardia; rt. thoracotomy, partial esophagectomy & esophagogastrostomy	Died on 6th postop. day, congestive heart failure
12.	Michaud	75	M	2 mo.	7/23/49	1951	Fibrosarcoma	Cardia	L. partial esophagogastrectomy	Original specimen lost; recurrence in 6 mo.; biopsy confirmed nature; died 3 mo. later
13.	Michaud	50	M	2 mo.	9/30/50	1951	Leiomyosarcoma	Lower third	L. partial esophagectomy and esophagogastrostomy	Satisfactory postop.; deep x-ray therapy
14.	Ovens and Russell	56	F	8 mo.	1951	1951	Squamous carcinoma and leiomyosarcoma	Mid third Lower third		Alive & well 25 mo. after operation
15.	Resano and Hojman	50	M	1 mo.	1951	1952	Leiomyosarcoma; diffuse	Upper third; fungating	Wookey procedure	Recovered; no metastases
16.	Borrie	63	M	1 mo.	4/ 9/52	1958	Fibrosarcoma	Lower third; polypoid	Partial esophagogastrectomy & esophagogastrostomy	Well 6 years after operation
17.	Gorbon	65	M	1½ yr.	6/30/52	1953	Fibrosarcoma	Lower third	L. partial esophagogastrectomy with esophagojejunostomy	Discharged on 18th day
18.	Creech et al.	62	M	3 mo.	6/28/54	1955	Leiomyosarcoma	Lower third	Rt. thoracotomy; partial esophagectomy & esophagogastrostomy	Satisfactory
19.	DeMuth	54	M	5 wk.	7/ 7/55	1956	Rhabdomyosarcoma	Lower third; polypoid	Partial esophagectomy & esophagogastrostomy	Survival

Maŭro and de Escobar,[13] in 1951, reported operating on a patient on Aug. 8, 1948, in whom, because of difficulty in defining the limitis of the growth when the esophagus had been freed, a Torek-type of resection was done instead of the usual esophagogastrostomy. The patient died on the eleventh postoperative day from bronchopneumonia.

Biasini's[14] patient, a woman aged 49 years, on Nov. 6, 1948, had resection of a growth in the lower third of the esophagus. On section it proved to be a fibroleiomyosarcoma.

Badosa-Gaspar and Boada,[15] on April 4, 1949, resected an ulcerative leiomyosarcoma of the middle third of the esophagus, measuring 6.5 by 4.5 cm. After preliminary supra-umbilical laparotomy and dilatation of the cardia, they performed a right thoracotomy through the sixth rib bed, followed by partial esophagectomy and esophagogastrostomy. Their patient, however, died on the sixth postoperative day from congestive heart failure.

Michaud's[16] initial patient was a man aged 75 years, who complained of dysphagia and was shown by esophagoscopy and fluoroscopy to have a growth at the cardia. On July 23, 1949, left partial esophagogastrectomy was performed. No histopathologic investigation was later available. Within 6 months the growth recurred, it was then proved to be fibrosarcoma, and the patient died within 3 months. It was therefore assumed that the original lesion was a fibrosarcoma.

His later patient was a man aged 50 years with a lower third growth successfully resected along similar lines on Sept. 30, 1950. As examination showed it to be a leiomyosarcoma, he also received a postoperative course of deep x-ray therapy.

Ovens and Russell,[17] in 1951, reported that their patient, a woman aged 56 years, was admitted to hospital with an 8-month history of dysphagia and 16 pound (7 Kg.) weight loss. Esophagrams revealed a constricting esophageal lesion at the level of the pulmonary vessels and, on esophagoscopy, at 32 cm. from the incisor teeth, a carcinoma was encountered. Through a left thoracotomy, partial esophagectomy with esophagogastric anastomosis was performed. The patient was discharged 28 days later.

Pathologic examination, however, showed the presence of two tumors, one a typical squamous carcinoma in the middle third of the esophagus, and the other, separated from the first by normal esophageal mucosa, was a leiomyosarcoma of the lower end of the esophagus at the junction of the cardio-esophageal mucosa. Neither extended beyond the muscularis nor were any regional lymph nodes invaded. The patient was alive and well 25 months postoperatively.

Burnett and St. John's[18] case, called by them a melanosarcoma, is clearly a true melanoma, and is excluded from this survey of sarcomas.

Resano and Hojman's[19] patient, a man aged 50 years, in 1951 gave a month's history of dysphagia. A vegetating growth at 20 cm. from the incisor teeth was shown to be a leiomyosarcoma. The growth was successfully resected from the cervical esophagus by the Wookey technique.

Gorbon[20] (1953) reported a man aged 65 years, with a growth infiltrating the lower esophagus and cardia, who had successful treatment by partial esophagogastrectomy with esophagojejunostomy on June 30, 1952. He was discharged well 18 days later. On histologic examination, the growth proved to be a fibrosarcoma.

Creech[21] and associates reported that a 62-year-old Negro, with a 3-month history of dysphagia, retrosternal and epigastric pain, with x-ray evidence of a polypoid tumor of the lower half of the esophagus, was shown at esophagoscopy to have a pedunculated leiomyosarcoma. On June 28, 1954, he had thoracotomy through the right fourth intercostal space. There was a freely movable sausage-shaped mass within the middle third of the esophagus. The esophagus was mobilized from the azygos vein to the diaphragmatic hiatus, the stomach freed through a midline abdominal incision, pyloromyotomy performed and esophagectomy and esophagogastrostomy. He was discharged on the fourteenth postoperative day, required dilatation of a stricture 2 months later, and thereafter remained well.

DeMuth[22] (1956) reported resecting the second rhabdomyosarcoma in world literature in a Negro aged 54 years. The patient gave a 5-week history of difficulty in swallowing solid foods accompanied by the loss of approximately 40 pounds in weight. Esophagrams and esophagoscopy revealed a growth 35 cm. from the maxillary border and histologic examination proved it to be a rhabdomyosarcoma. On July 7, 1955, via a left thoracotomy, partial esophagectomy with esophagogastric anastomosis was performed. He was discharged on the nineteenth postoperative day.

With the following case report, therefore, nineteen esophageal sarcomas treated surgically were available for study. They included 7 fibrosarcomas, 7 leiomyosarcomas, 3 rhabdomyosarcomas, one fibroleiomyosarcoma, and one described as "sarcoma polymorphocellular."

CASE REPORT

J. F. D., aged 63 years, was admitted to Green Lane Hospital, Auckland, on May 17, 1951, for surgical treatment of an hiatal hernia, which esophagrams had shown to extend approximately 5 cm. above the diaphragm (Fig. 1). Esophagoscopy confirmed reflux but showed no other lesion.

Transthoracic hiatal herniorrhaphy was performed on May 23, 1951. The edges of the hiatus were defined and the hernial orifice found to take three fingers alongside the esophagus. The wall of the stomach and lower esophagus was palpated, but there was no suggestion of any tumor. His convalescence was smooth. Esophagrams on June 11, 1951, in both the erect and head-down positions, confirmed a normal esophagus and a satisfactory hiatal repair, and the patient was discharged fit on June 12, 1951.

When seen for the first time by the writer on Jan. 18, 1952, during a routine follow-up examination, he was symptomless, although an esophagram was suggestive of neoplasm (Fig. 2). Within 6 weeks, he developed dysphagia, which took the form of a sharp pain behind the lower end of the sternum on swallowing. Esophagrams on March 26, 1952, revealed a constant, large irregular filling defect lying in the lower third of the esophagus. The barium flowed unobstructed and in a thin stream over the surface of the mass, suggesting the presence of a single polypoid tumor (Fig. 3).

The esophagus was next fully mobilized up to the level of the inferior pulmonary vein. It was transected well above the growth, and the specimen was removed.

He was readmitted to hospital on April 1, 1952. An esophagoscope passed easily into the stomach and, as the instrument was withdrawn to 40 cm. from the upper jaw, the smooth surface of the growth was clearly seen on the posterior esophageal wall. The growth was estimated to measure 2.5 by 2.0 cm. When a biopsy was taken, the lesion bled freely. Initial histologic examination suggested an anaplastic carcinoma.

Operation.—On April 9, 1952, transthoracic partial esophagogastrectomy was performed by the writer. The technical details follow.

The left chest was opened through the left ninth intercostal space. Adhesions between the base of the left lung and dome of the diaphragm from the previous operation were divided, as was the left pulmonary ligament. The parietal pleura from over the aorta beside the lower third of the esophagus was mobilized, reflected medially, the lower third of the esophagus was isolated, and a catheter sling passed around it.

The abdomen was next opened through a radial diaphragmatic incision. No palpable metastases were detected in the liver, stomach, pelvis, or regional lymph nodes. The growth could be felt lying in the lumen of the lower third of the esophagus. It was decided to perform a block resection of the lesion as described by Allison and the writer.[23]

Fig. 1.—Esophagram of May 22, 1951, showing an hiatal hernia.

An incision was made to the left of the spleen in the plane of zygosis between spleen and body of pancreas on the one hand, and dorsal abdominal wall on the other side. The stomach bed was next mobilized medially. The great omentum was divided from the transverse colon. The collar of diaphragm was taken from around a tightly repaired hiatus. The splenic artery and vein were divided, and the pancreas transected at the junction of neck and body. The stump was buried in residual soft tissue. The left gastric artery was next ligated and divided. The stomach was obliquely transected from the greater curvature down to the lesser curvature, thereby removing the proximal half of stomach and the lymphatic sump around the left gastric artery. The lower half of the stomach was completely closed with two layers of continuous chromic catgut sutures.

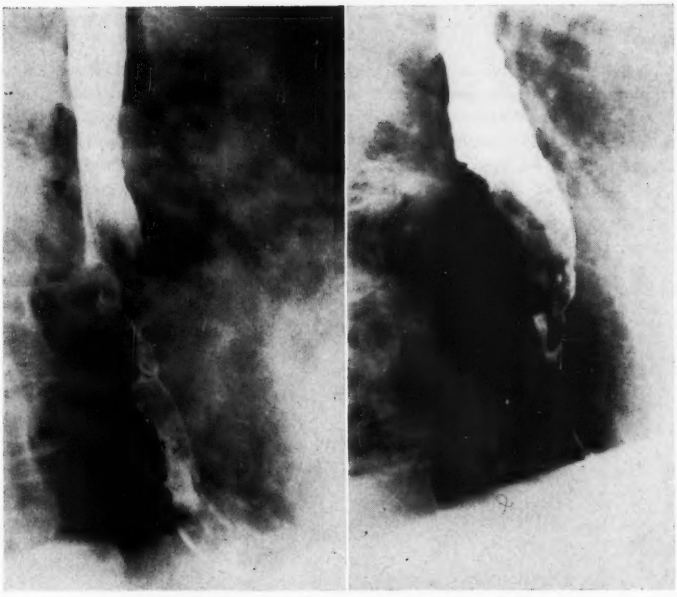

Fig. 2. Fig. 3.

Fig. 2.—Esophagram of Jan. 23, 1952, suggesting neoplasm in the lower third of the esophagus.

Fig. 3.—Esophagram of March 26, 1952, showing a constant, large, irregular filling defect in the lower third of the esophagus.

Fig. 4.—Esophagram on May 6, 1952—27 days after operation—showing intrathoracic esophagogastrostomy.

Through a seventh intercostal space incision, a two-layer subaortic anastomosis was made between the distal half of the stomach and midesophagus, using interrupted chromic catgut sutures. Some omental tissue was lightly sutured around the anastomosis. The diaphragm was loosely approximated around the stomach, and the remaining diaphragmatic tissue was closed with interrupted sutures. The left lung was inflated and the chest closed in layers over water-seal drainage.

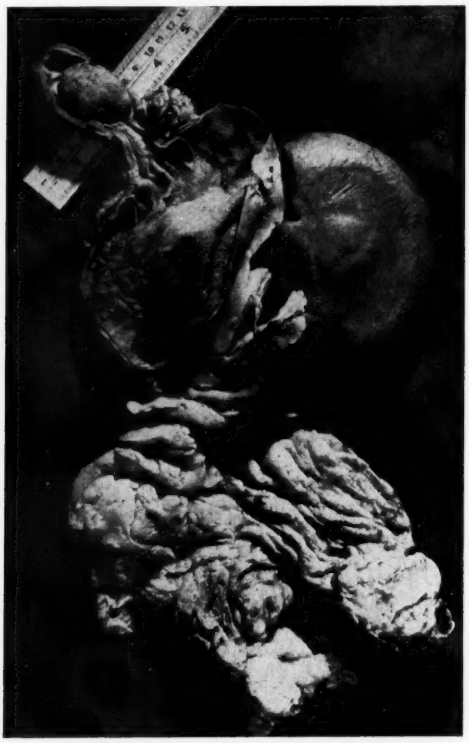

Fig. 5.—Specimen consisting of the lower third of the esophagus and polypoid tumor (lying on the rule) together with the proximal half of the stomach, stomach bed, spleen, omenta, and left half of pancreas.

Progress.—The patient's convalescence was uneventful. He took sips of water by mouth after 24 hours, 1 ounce of water per hour on the second day, he doubled this diet on the third day, and took fluid drinks until the tenth day. Thereafter, he took a light diet, progressed to solid food, and esophagrams made on May 6 showed a satisfactory esophagogastric junction. He was discharged fit on May 7, 1952, 28 days after operation.

Follow-up (Courtesy Mr. David Cole).—On May 10, 1957, although thin, he was well, had no pain, no dysphagia, no flatulence, nor regurgitation. There were no clinical signs of recurrence. Recent esophagrams showed that the anastomosis function satisfactorily, and there was no delay to the passage of thick or thin barium. On May 7, 1958, 6 years after operation, he remained well.

Pathology (Courtesy Dr. Stephen Williams).—(Fig. 5) The specimen consists of the lower one third of the esophagus (8 cm. in length), the stomach, the spleen, the left half of the pancreas, and the omentum. A fringe of diaphragm is attached to the specimen at the cardio-esophageal junction, showing a healed, repaired hiatus. Situated in the esophagus there

is a somewhat pedunculated oval tumor, measuring 4.0 by 2.8 by 2.0 cm., attached by a broad base to the posterolateral wall of the esophagus. The upper line of excision in the esophagus is 3.0 cm. from the upper pole of the tumor. The tumor is a firm, finely lobulated, grayish mass showing some superficial ulceration and exudation. No enlarged lymph nodes are found in the specimen, but several small nodes lying in the paraesophageal mediastinal tissues are revealed by section. There is no evidence of metastic involvement.

Fig. 6.—Photomicrograph (low power) of the lesion, confirming fibrosarcoma.

Histology.—(Fig. 6) Blocks were taken from the tumor, from two representative lymph nodes, and from the esophagus at the upper line of excision. These show the tumor to be a moderately well-differentiated fibrosarcoma composed of irregular spindle-shaped cells, arranged in sheets lying in different planes. The nuclei show considerable variation of size and shape and include numerous mitoses. The surface layers of the tumors are necrotic and acutely inflamed. A Van Gieson stain confirms the fibrous nature of the tumor, which infiltrates the esophageal wall, penetrating the muscularis mucosa, but not involving the muscle layers. In the submucosa, the tumor tissue becomes continuous with an abnormal development of dense fibrous tissue, presumably scar tissue from previous ulceration.

The esophagus at the line of excision and both lymph nodes show no evidence of malignant infiltration.

The diagnosis therefore is a fibrosarcoma of the esophagus apparently arising from dense submucous scar tissue. There is no evidence of local metastatic spread.

DISCUSSION

In the writer's experience, dysphagia after hiatal herniorrhaphy is not uncommon. It is usually acute in onset, arising within a month of operation, and almost always due to a bolus of poorly chewed food plugging the esophageal lumen at the level of the tightened hiatal orifice. Occasionally, it has been due to a fibrous esophageal stricture developing secondarily to the preoperative reflux esophagitis.

The delay in onset of postoperative dysphagia, in this case report, for 8 months after successful hiatal herniorrhaphy is long for such benign causes. It underlines again the fundamental surgical principle that dysphagia, no matter when it arises, be it an initial symptom or one after a successful esophageal operation, cannot be ignored, and that the patient requires prompt, careful, and complete investigation by both esophagrams and esophagoscopy to establish the cause. The one without the other tells only half the story. As the evidence of the esophagrams of January, 1952, was not fully appreciated and, as at that time there was no dysphagia, esophagoscopy was delayed 2 months until the patient's next visit, by which time dysphagia had been present for one month. Had the suggestion of aberration in the January esophagrams been followed up and esophagoscopy performed, the lesion would almost certainly have been detected then.

An analysis of the 19 published surgical cases, found after a thorough review of the world's literature, shows that the ages varied from 43 to 78, with a mean of 58 years. When grouped according to decades, the ages at operation were: 40-49, 4 cases; 50-59, 6 cases; 60-69, 7 cases; and 70-79, 2 cases. Of these, 5 were in females and 14 in males.

The duration of dysphagia varied considerably from one month in the writer's patient, up to 1½ years as reported by Gorbon. Certainly, critical study of those patients having operation does not support the contention of Thorek and Neiman that sufferers from esophageal sarcoma rarely live beyond 6 months. Harrington's patient, with a year of dysphagia, was reported well 7 years later. Lyons and Garlock's patient, alive and well 7 years after resection of a polypoid growth, also had preoperative dysphagia for a year, as did 2 other patients treated surgically.[13, 14]

The pathologic type of the growth need not be a guide to prognosis for, although in the writer's case there was no deep extension from the pedicle of the polypoid sarcoma into the esophageal wall, Harrington reported one, polypoid in type, which had infiltrated widely into the mediastinum when explored.

The site of those lesions treated surgically has varied widely, from one in the upper third of the esophagus, one in both upper and middle thirds, six in the middle third alone, to eleven in the lower third. When present, the x-ray finding of breaking up or "splitting up" of the barium by the growth is a characteristic x-ray feature, as is a peculiar soap-bubble effect, originally described by Allison.[24, 25] Esophagoscopy and biopsy usually establish the true nature of the lesion.

Lower third growths are best treated by the left-sided transthoracic approach with resection and esophagogastrostomy.

Middle and upper third growths may be treated either by the right or left transthoracic approach, according to the surgeon's preference. As with carcinomas, there is an increased operative mortality with these higher lesions.

The patient reported by the writer had block dissection of the regional lymph channels by the technique previously described.[23] although no regional lymph nodal invasion was detected at subsequent pathologic examination, nevertheless the initial satisfactory convalescence and pleasing long-term freedom from recurrence or metastases do lend support to the attitude that in treating neoplasms in the lower third of the esophagus, a deliberate block dissection should be the proper approach to the problem.

The details of pre- and postoperative management follow general lines established for resection of the esophagus for carcinoma.[26]

Four patients died from the effects of operation. As complete long-term follow-up reports of all the remaining 15 cases are not available, it is not possible to generalize on prognosis after operation.

Suffice it to say that, if the patient is otherwise healthy, the lesion localized, and the surgical treatment adequate, the prognosis appears to be good, and that at least 3 patients have now lived more than 6 years after such treatment.

SUMMARY AND CONCLUSIONS

The literature for surgical treatment of sarcoma of the esophagus is briefly reviewed, and a case of polypoid fibrosarcoma of the lower third of the esophagus, discovered 8 months after transthoracic repair of an hiatal hernia and one month after onset of dysphagia, is reported. The patient was treated by partial esophagogastrectomy with esophagogastrostomy and block dissection of the regional lymph nodes. He is alive and well 6 years later.

From an extensive search of the literature, 19 resections for sarcoma of the esophagus were discovered, of which this is chronologically the sixteenth in which surgical treatment was used.

The evidence available suggests that the lesion was not present at the time of the hiatal herniorrhaphy. Its discovery 8 months later emphasizes that esophageal tumors—often symptomless—can and do occur in association with an hiatal hernia, that all patients with hiatal hernias should have a preoperative esophagoscopy, and that recurrence of dysphagia after apparently successful hiatal herniorrhaphy should not be ignored but be promptly, carefully, and repeatedly checked by esophagoscopy as well as esophagrams.

Sarcoma of the esophagus, although rare, should be borne in mind and, if detected early enough and of polypoidal type, it is amenable to successful resection, with an excellent prognosis.

ADDENDUM

The patient remains well 6 years and 9 months after operation.

I am happy to record my obligation to Mr. Douglas Robb, Surgeon-in-charge, Cardio-Thoracic Unit Green Lane Hospital, Auckland, where the patient was treated, and I gratefully acknowledge photographic help from Mr. Litherland, Medical Photographer, Auckland Hospital, and help in obtaining microfilms of the rarer references by Mr. H. D. Erlam and Miss E. Murray, Medical Library, Medical School, University of Otago, Dunedin. I am indebted to Miss N. Richardson for secretarial help and to Mr. Gerald Brookes, of the University of Otago, for further preparation of the illustrations.

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EPIDERMOID CARCINOMA IN MUCOSA OVERLYING A PEDUNCULATED LIPOMA OF THE ESOPHAGUS

Raul A. Marcial-Rojas, M.D., and Pedro Suau, M.D.,***
San Juan, Puerto Rico

THE subject of benign tumors of the esophagus is rapidly dismissed in most textbooks of pathology, medicine, gastroenterology, and bronchoesophagology. The descriptions are usually limited to a few sentences, always emphasizing their infrequency, and usually enumerating the several histologic types which have been sporadically reported in the literature. Upon a careful review of the literature, one is impressed with the repetition of the statement that benign neoplasms are extremely rare, there are few recorded cases, thus they deserve very brief mention. In 1926, Vinson and his co-workers[1] mentioned the occurrence of only three benign esophageal tumors among approximately 4,000 patients complaining of dysphagia. Practically all publications deal with individual case reports.[2-16] In 1932, Patterson[11] presented one case and reviewed the literature. He was able to find 61 instances of benign tumors of the esophagus in a period of time extending from 1717 to 1932. He mentioned only two lipomas.

In 1953, Stout and his colleagues[17] classified 103 benign tumors of the esophagus as intraluminal and intramural. The former could be sessile or polypoid and the latter solid or cystic. Most of the polypoid tumors were considered by them to be fibrous polyps secondary to hyperplasia of the subepithelial tissues and to assume their pedunculated structure aided by the action of peristalsis. Some of the polypoid tumors were also lipomas, fibrolipomas, and even leiomyomas. The immense majority of the intramural tumors were leiomyomas.

Malignant degeneration of a benign esophageal tumor is so infrequent as to almost constitute a pathologic curiosity. Feldman[2] reported an adenocarcinoma apparently arising in an adenomatous polyp of the esophagus. Stout and Lattes[18] refuse to accept this case as valid in view of the fact that only a small biopsy was performed. We are of the same opinion. Probably the most frequent example of malignant degeneration of a benign esophageal tumor is exemplified by leiomyoma. It constitutes the most frequently encountered benign

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*Professor and Chairman, Department of Pathology, University of Puerto Rico School of Dentistry, Pathologist to Dr. I. González Martínez, Oncologic Hospital, San Juan, P. R.

**Assistant Clinical Professor in Surgery, University of Puerto Rico, School of Medicine, San Juan, P. R.

tumor of the esophagus and it is possible that some of the leiomyosarcomas may have arisen from previously existent leiomyomas. One of these cases is suggested by Puestow and co-workers.[12] It was a polypoid leiomyosarcoma, and he assumed from the clinical history of long symptomatology that it developed from a pre-existent leiomyoma.

The simultaneous occurrence of benign and malignant tumors of the esophagus is rare.[19] The invasion of a fibrous polyp by an epithelioma is recorded by Targett.[20] Schirmer[21] observed an ulcerating carcinoma in close proximity to a pedunculated lipoma near the cardiac end of the esophagus. Callanan[22] reported, in 1954, the simultaneous occurrence of a small intramural leiomyoma and an overlying squamous-cell carcinoma. He claimed it constituted the first case of this simultaneous occurrence reported in the literature. Puestow[12] in 1955 reported a similar case of squamous-cell carcinoma of the esophagus with an underlying small intramural leiomyoma. An example of an epidermoid carcinoma of the mucosa overlying a pedunculated fibrous polyp is shown by Stout[18] in his fascicle on esophageal tumors.

The purpose of this communication is to report on an instance of a pedunculated esophageal lipoma with an epidermoid carcinoma of the overlying esophageal mucosa. This apparently constitutes the fifth instance in the literature of associated benign and malignant tumors of the esophagus and the second one of a pedunculated lipoma and epidermoid cancer.

CASE REPORT

A 63-year-old white man who had been complaining of a sore throat and slight pain in the left side of the neck for the previous 5 months was admitted to the Presbyterian Hospital for laryngoscopic examination on May 8, 1957. He had visited a physician on several occasions during that period of time. Pathologic changes which could explain the sore throat and the cervical pain were never encountered until his last visit when a nontender, movable mass, 4 cm. in main diameter, was found in the left side of the neck.

The laryngoscopic and nasopharyngoscopic examinations were negative. A slightly suspicious lesion in the left side of the base of the tongue was biopsied. The pathologic examination failed to disclose the presence of neoplasia. A chest film was negative.

On May 22, he had an excisional biopsy of the cervical mass. A frozen section revealed metastatic epidermoid carcinoma in a cervical lymph node. When the patient was recovering from the anesthesia he coughed and a large pedunculated mass protruded from the left angle of the mouth. It showed an ulcerated lesion on its most distal portion. Before anything could be done the patient swallowed the mass again.

A barium meal was given to the patient on May 29 which disclosed a markedly dilated esophagus occupied by a pyriform mass (Fig. 1). The distal portions of the mass were encountered at the level of the cardioesophageal junction. An esophagoscopic examination was performed and the bulk of the tumor was encountered in the distal third with the pedicle attached to the cervical esophagus.

On June 8, a cervical esophagotomy was performed and the polyp was excised at its junction with the cervical esophagus. A frozen section showed the epidermoid carcinoma on the surface of the lipoma at its distal portion. A left radical neck dissection was also performed.

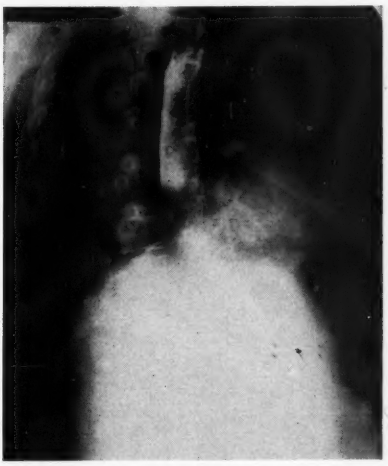

Fig. 1.—Barium swallow disclosing the marked dilatation of the esophagus by the polypoid tumor. The lowermost portion of the tumor rests on the cardioesophageal junction.

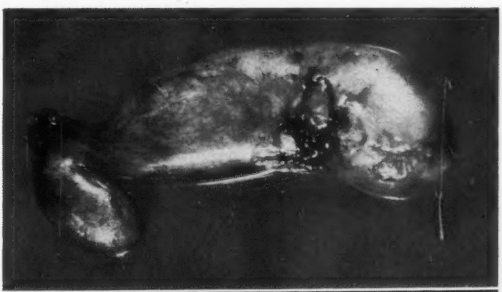

Fig. 2.

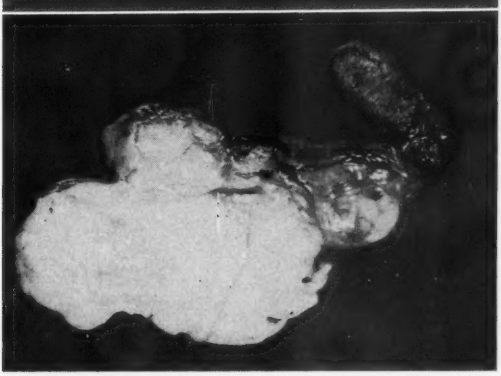

Fig. 3.

Fig. 2.—The polypoid lipoma with the ulcerated epidermoid carcinoma in the overlying mucosa. Note the smaller lipoma attached to the same pedicle.

Fig. 3.—The bisected lipoma showing the ulcerated carcinoma infiltrating the most superficial portions.

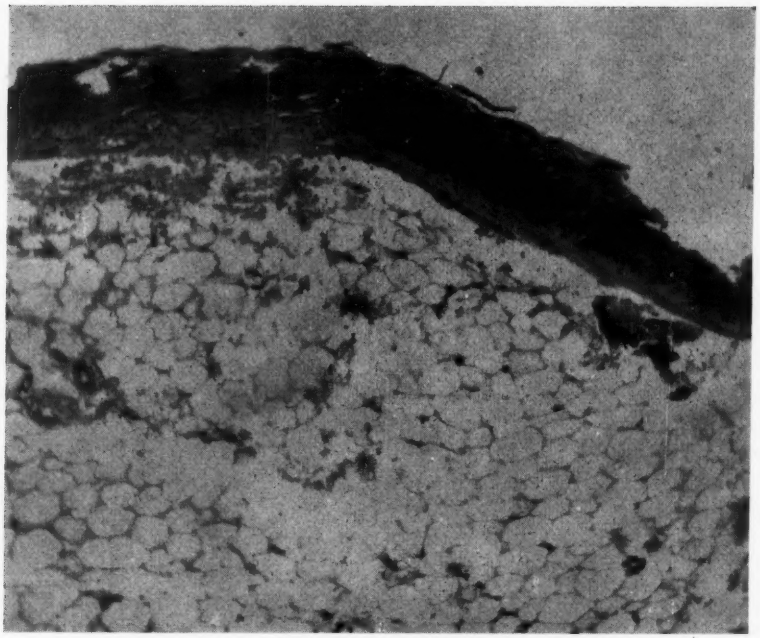

Fig. 4.—Section of the lipoma covered by esophageal mucosa (hematoxylin and eosin; ×100).

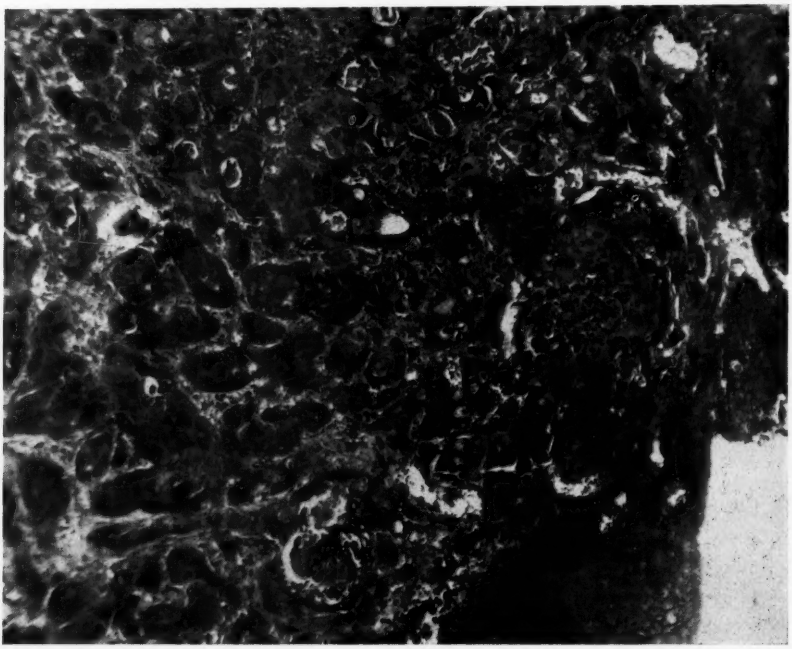

Fig. 5.—Epidermoid carcinoma arising from esophageal mucosa and infiltrating the subepithelial tissues (hematoxylin and eosin; ×360).

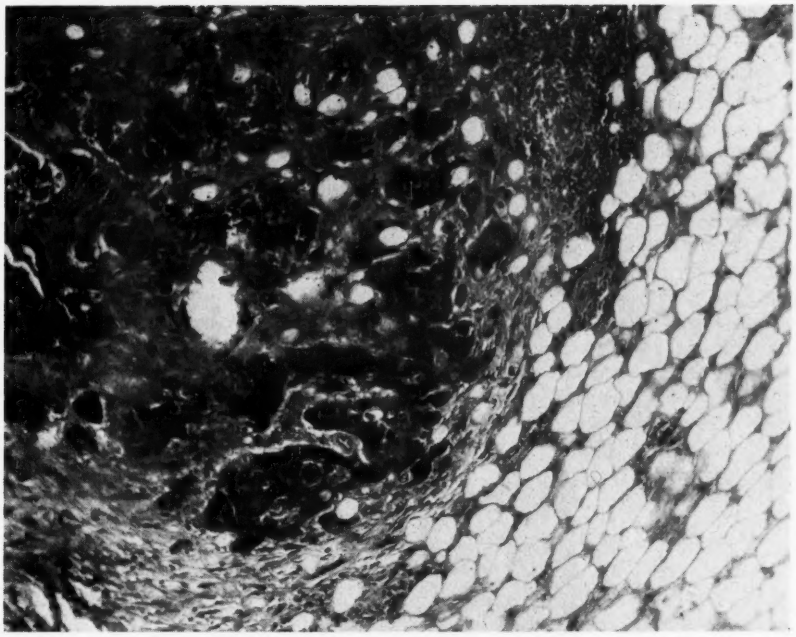

Fig. 6.—Epidermoid carcinoma infiltrating into the substance of the lipoma (hematoxylin and eosin; ×360).

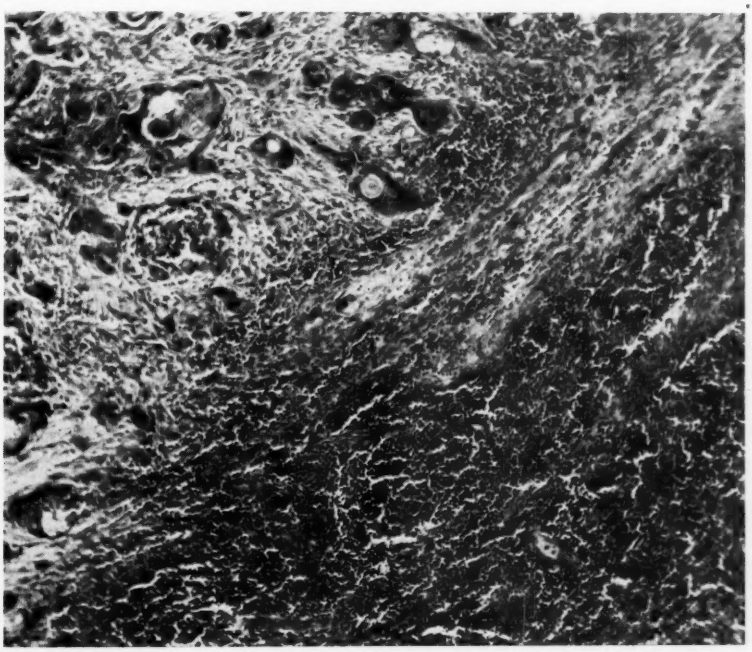

Fig. 7.—Metastatic epidermoid carcinoma in the only affected cervical lymph node (hematoxylin and eosin; ×360).

Pathologic Findings.—

Gross description: The polypoid mass measured 11 by 3.5 cm. and was covered for the most part by normal esophageal mucosa (Fig. 2). A smaller but similar mass was attached to its pedicle and measured 3 by 1.5 cm. On cut surface, both the large and small polypoid masses were composed of yellowish adipose tissue with minimal areas of fibrosis (Fig. 3). The esophageal mucosa covered both pedunculated lipomas except for an ulceration on the distal and anterior portions of the larger one. This ulcer measured 2.5 by 1.5 cm. and beneath it the subepithelial tissues were infiltrated by grayish-white neoplastic tissue for a distance of 2 mm. The contents of the radical neck dissection were carefully studied and 28 lymph nodes were recovered. None of them showed metastatic carcinoma.

Microscopic description: The polypoid tumors were pedunculated lipomas with some areas of fibrosis (Fig. 4). The ulcerated lesion was an epidermoid carcinoma, grade 2, which infiltrated the subepithelial tissues and the substance of the lipoma (Figs. 5 and 6). The line of resection at the pedicle was free of tumor. It is of interest to note that none of the cervical lymph nodes showed metastatic tumor. Apparently the only lymph node affected was the one removed for biopsy (Fig. 7).

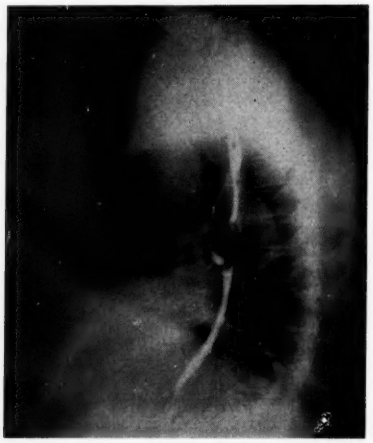

Fig. 8.—Barium swallow shows the area of stenosis at the cervical esophagus due to persistent carcinoma.

The patient recovered very nicely from the surgical procedure except for a small salivary fistula that healed spontaneously. Four months after the operation he was re-admitted to the hospital because of progressive dysphagia and sialorrhea. A barium swallow disclosed an area of stenosis at the site where the polypoid mass had been removed from the cervical esophagus (Fig. 8). The possibility of scarring and stenosis was considered. A biopsy from that area revealed an epidermoid carcinoma of similar histology as that found on the pedunculated lipoma. The patient was submitted to radiotherapy. A gastrostomy had to be performed as the disease progressed rapidly and became uncontrollable. The last time that the patient was seen he was deteriorating rapidly and showed obvious clinical evidence of persistent disease.

DISCUSSION

This is a most unusual case of the simultaneous occurrence of a benign and a malignant tumor of the esophagus. An infiltrating epidermoid carcinoma developed in the mucosa overlying a pedunculated lipoma of the esophagus.

The tumor metastasized precociously to one cervical lymph node and recurred at the site of removal of the pedicle in the cervical esophagus. As multiple sections of the lipoma through the pedicle failed to disclose carcinoma we must postulate with reasonable certainty that, when the pedicle was ligated at the cervical esophagus, a tumor embolus must have been caught in transit to the cervical lymph nodes and was retained there by the suture.

The case also emphasizes the fact that no matter how minimal is the symptomatology referable to the esophagus in a case of metastatic carcinoma to cervical lymph nodes of unknown origin, a barium swallow and even an esophagoscopy should be done as part of the routine procedure to detect the concealed lesion.

SUMMARY

1. A review on the subject of benign tumors of the esophagus with particular interest in the simultaneous occurrence of benign and malignant lesions has been presented.

2. The case represents the fifth instance of this simultaneous occurrence of benign and malignant tumors of the esophagus and the second one of a pedunculated lipoma and an epidermoid carcinoma.

The authors are most grateful to Dr. José Noya Benítez, Professor of Surgery of the University of Puerto Rico Medical School, and to Dr. José Picó, Professor of Otorhinolaryngology of the same institution, for their valuable help and advice in the management of this case.

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"AIR PLOMBAGE" WITH RESECTION FOR PULMONARY TUBERCULOSIS: A TECHNIQUE FOR DECREASING COMPLICATIONS

James W. Pate, M.D., Felix A. Hughes, Jr., M.D., Roger E. Campbell, M.D., and John M. Reisser, M.D., Memphis, Tenn.

THE COMPLICATION rate following pulmonary resection for tuberculosis is disturbingly high, although the mortality is low (about 0.5 per cent). In an attempt to find a practical method of lowering the complication rate, 61 upper lobe pulmonary resections for tuberculosis with concomitant "air plombage" were performed and this group is contrasted with a series of 313 consecutive upper lobe resections for tuberculosis not accompanied by any collapse procedure.

Numerous different techniques have been tried in an attempt to prevent complications after pulmonary resections. In 1953, Chamberlain[1] mentioned the use of "extraperiosteal plombage of the patient's subscapular collection of blood" in a few segmental resections. Since then, we have used a similar technique, which we call "air plombage" in some of our cases. A search of the literature has failed to reveal an evaluation of this procedure.

TECHNIQUE

Distribution of the two groups is shown in Tables I and II.

After the pulmonary resection is completed and the intrapleural tubes are in place, the pleura and intercostal muscles and fascia are closed in the routine manner. An estimate is made, before closing, of the amount of lung tissue removed, the location and shape of the remaining lung and the degree of pleural filling which the lung will easily assume without overexpansion. If the remaining lung does not fill the pleural space with ease, or if large raw surfaces remain in a plane which cannot easily contact the chest wall, or if there is an excessive air leak from the parenchyma, the decision to do an air plombage is made. Portions of the first, second, third, and usually the fourth ribs are stripped subperiosteally, leaving attached periosteum on their outer surfaces. The size, shape, and location of the resultant pocket is made to fill

From the Thoracic Surgery Section, Surgical Service, Veterans Administration Medical Teaching Group Hospital, Memphis 15, Tenn.

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the defect left by the pulmonary resection. The pleura, periosteum, and intercostal muscles and facia drop in to contact the resected surface of the lung. No drainage of this space is done. The chest wall is then closed in anatomic layers.

After surgery, the air pocket will slowly fill with blood and fibrin. It will decrease in size as the lung heals and the pleura will be pushed up by the expanding lung until little if any evidence of the plombage remains (Figs. 1 and 2).

TABLE I

	WITHOUT AIR PLOMBAGE	WITH AIR PLOMBAGE	TOTAL
Lobectomy	116	32	148
Segmental	123	22	145
Wedge	74	7	81
Total	313	61	374

TABLE II

SEGMENTS REMOVED	WITHOUT AIR PLOMBAGE PER CENT	WITH AIR PLOMBAGE PER CENT	TOTAL PER CENT
Apical	13.9	3.3	17.2
Apicoposterior	26.0	4.2	30.2
Lobectomy	36.8	5.3	42.1
Posterior	4.7	0.9	5.6
Apicoposterior and superior	3.9	0.3	4.2
Total	85.3	14.0	

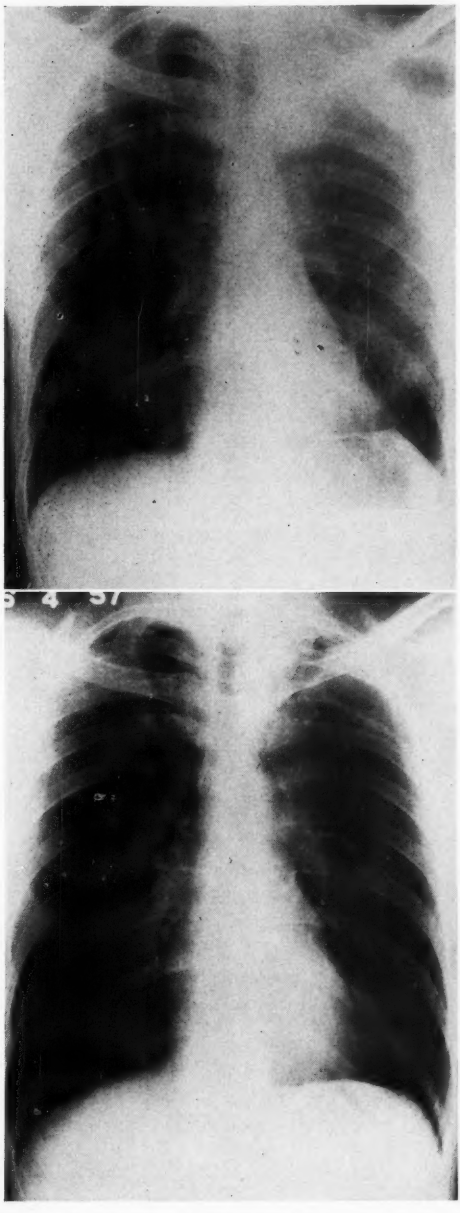
RESULTS

A comparison of the complication rates in the two series is presented in Table III. There was only one death (0.3 per cent) in the entire group, and that due to myocardial infarction.

TABLE III. COMPLICATIONS

	OPERATION			
	LOBE	SEGMENT	WEDGE	TOTAL
	Without Air Plombage			
Number of cases	116	123	74	313
Number of complications	24	28	8	60
% Complications	20.7	22.8	10.8	19.3
	With Air Plombage			
Number of cases	32	22	7	61
Number of complications	1	0	0	1
% Complications	3	0	0	1.6

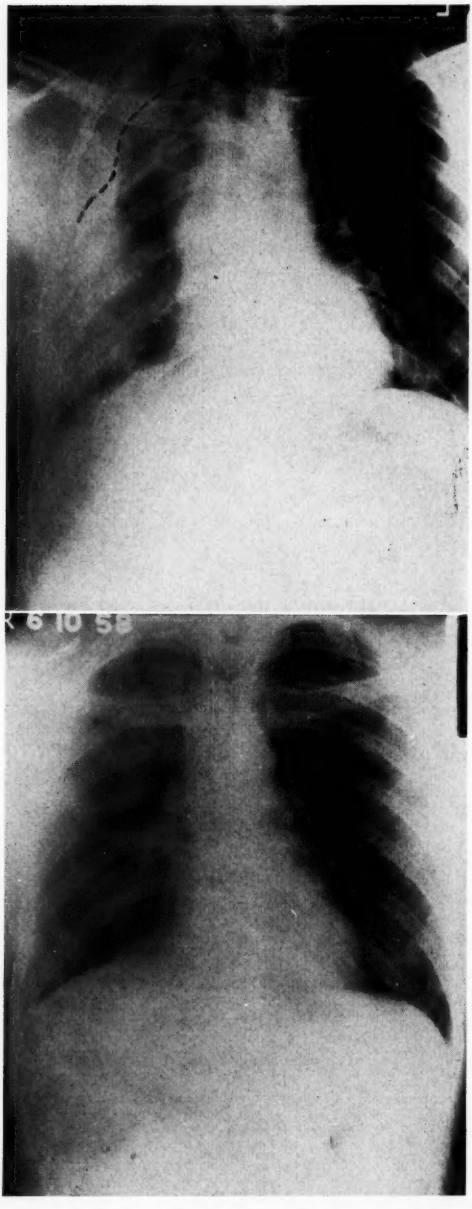
The complication rates were high, but this is due to the fact that (1) only upper lobe surgery is analyzed here (the rate for middle and lower lobe resections is lower), (2) all complications are included ("residual air space" of more than 2 weeks' duration is considered to be proof of a bronchopleural fistula), (3) only 30.8 per cent of the patients were original treatment cases, (4)



A.

B.

Fig. 1.—*A*, X-ray of chest 4 days after a left upper lobectomy and air plombage. *B*, X-ray of same patient 10 months later.



A.

B.

Fig. 2.—*A*, X-ray of chest one day after a right upper lobectomy and a large air plombage. The dotted line shows the edge of the plombage space. *B*, X-ray of the same patient 3 months later.

70 per cent of the patients had open cavities resected (there were few "nubbins" removed), (5) 17.2 per cent of the patients had had previous major chest surgery, and (6) 76.3 per cent gave positive sputa within 3 months prior to surgery.

The complication rate was quite different in the two series. The difference between a total complication rate of 19.3 per cent and a rate of 1.6 per cent is statistically significant and clinically impressive. The statistical comparison is further emphasized by the number of postresection thoracoplasties required to deal with fistulas, empyema, etc.

Forty-one (13 per cent) of the patients with resections unaccompanied by air plombage required later thoracoplasty to deal successfully with complications. An additional 3 patients had subsequent decortication. Thus, a total of 14 per cent of this group required later major surgery to handle the complications of pulmonary resection. On the contrary, only one (1.6 per cent) of the patients with resection who had air plombage required thoracoplasty, and none, decortication.

The complication rate for apical and posterior segmental resection was 15 per cent. Upper lobectomy gave the same incidence of complications. Apical segmental resection was followed by complications in 8.5 per cent, and apical-posterior-superior lower lobe resections produced 7 per cent complications. Posterior segment resection alone was followed by complications in 3 of 16 cases, and apical-superior segment in 2 of 3 cases. The only complication in the group with air plombage was in a right upper lobectomy with anomalous arterial supply (Table IV).

TABLE IV. TYPES OF COMPLICATIONS
(CASES WITHOUT AIR PLOMBAGE)

	OPERATION				
	LOBE	SEGMENT	WEDGE	TOTAL	PER CENT
Bronchopleural fistula	13	14	3	30	9.5
Empyema	1	5	1	7	2.2
Spread	2	1	0	3	0.9
Hemorrhage	5	3	0	8	2.5
Tuberculous wound infection	1	1	0	2	0.6
Others	8	5	4	17	5.2
Total	30	29	8	67	21.2

Note: Some patients had more than one complication.

From these figures, it appears that air plombage is especially valuable in resections involving the apical and posterior segments and in upper lobectomy. It is of some value when either the apical or posterior segment alone is resected.

We believe that a resection involving one or more segments of the upper lobe along the superior segment of the lower is especially vulnerable to complications, and that, therefore, air plombage is indicated in this group.

DISCUSSION

Bronchopleural fistula (or "residual air space") remains the most frequent and one of the most troublesome of the complications of pulmonary resections. This is especially true following surgery on the upper lobe, particularly in tuberculosis patients.

Several factors appear to lead to an increase in incidence of fistula. These include: (1) *Active disease* at the line of resection. (2) *Technical errors* in dealing with the lung tissue (this seems to be in regard to the minute bronchi in the parenchyma rather than the bronchial stump itself). (3) *Dead space* due to fibrosis in the lung with decreased compliance preventing the lung from filling the pleural space; or a total air leak (usually in the lung surface) sufficiently large to prevent a negative intrapleural pressure from expanding the lung; or a gross discrepancy in the shape of the intrapleural space and the lung surface, causing air pockets to be trapped, such as in the apex after an apical segmental resection.

Air plombage was developed to prevent the formation of an intrapleural pocket of dead space. If properly performed it does this in several ways. First, it allows relatively healthy tissue to fall against the raw surface at the line of resection. This tends to seal multiple minute air leaks, and aids healing by preventing overexpansion which may result in persistent leaks and active disease. Second, it gives the chest wall a controlled amount of flexibility, thus preventing an excessive intrapleural negative pressure during forced or rapid inspiration, which tends to keep small bronchi open. Third, the procedure "tailors" the shape of the intrapleural space to fit that of the lung so that a fibrosed or noncompliant lung with abnormal shape resulting from resection will touch the pleura at all points and most importantly at its raw surface, thus obliterating the pleural space.

A satisfactory air plombage must (1) result in an extrapleural pocket of about the same volume as the resected pulmonary tissue, and (2) be so located that the shape of the intrapleural space is the same as that of the remaining lung surface.

Needless to say, the stripped portion of the chest wall must be intact to prevent intrapleural contamination from entering the space with resultant infection.

While these same factors may be produced by a concomitant thoracoplasty (with about the same results), air plombage has several additional advantages. First, it results in no bony deformity or scoliosis; second, it is faster and less traumatic than thoracoplasty; third, it is somewhat automatically reversible, for, after all air leaks are sealed and the raw surface is healed, the lung will expand, pushing the stripped area back against the ribs and thus obliterating the space. Fourth, the presence of blood, fibrin, and trapped air in a closed space covered by the bony cage will prevent excess paradoxical motion even when a large space is created. This allows a much larger stripping with a greatly simplified postoperative course than would be obtained with a thoracoplasty.

SUMMARY

1. A group of 61 upper lobe resections with concomitant air plombage is compared with 313 upper lobe resections without a collapse procedure.

2. The *over-all* complication rate was 19.3 per cent in the group without air plombage, but only 1.6 per cent in the group in which air plombage was done.

3. Without a concomitant collapse procedure, 14 per cent of the patients required further surgery for the treatment of complications, contrasted with only 1.6 per cent of the group with air plombage.

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SPACE PROBLEMS IN EXTENSIVE RESECTION FOR PULMONARY TUBERCULOSIS: THE USE OF PRE-RESECTION TAILORING THORACOPLASTY

Frank J. Milloy, M.D., Ahmed Kahdem, M.D., and Hiram T. Langston, M.D., Chicago, Ill.*

THE ANATOMIC distribution of pulmonary tuberculosis is frequently such that extensive resection of the upper portion of the lung is necessary. One of the requirements for success in these segmental or lobar resections is that the remaining pulmonary tissue be capable of filling the pleural space. If this requirement is not met, an unfilled space results which may well become the location of an empyema.

In a recent report, Bell[1] found 30 instances of postresection space problems in 135 lobectomies, an incidence of 22 per cent. Wareham and his co-workers[5] found, in a group of 55 lobectomies, twelve persistent pleural spaces, an incidence of 20 per cent and, in a group of 22 patients who underwent lobectomy plus segmentectomy or wedge resection, nine persistent pleural spaces, an incidence of 40 per cent. Although, they emphasized that some of these spaces remained uncomplicated, many required further surgical intervention.

The space resulting from resection of a portion of the lung is ordinarily obliterated by one or both of two processes. These are overexpansion of the remaining lung tissue and decrease in the size of the hemithorax. Decrease in the size of the hemithorax is produced physiologically by mediastinal shift, narrowing of the intercostal spaces, and/or a rise in the level of the diaphragm. If these physiologic compensatory mechanisms are insufficient, surgical measures may be taken to decrease the size of the hemithorax, such as paralysis of the diaphragm, creation of a "pleural tent," or the performance of some type of thoracoplasty.

If thoracoplasty is required as an adjunct to pulmonary resection, it may be performed (1) concomitant with resection, (2) following the resection, or (3) preceding resection.

1. *Concomitant Thoracoplasty.*—In most of the patients operated upon in this institution there has been severe apical disease with dense pleural adhesions, and we have frequently found it necessary to use extrapleural and

From the Chicago State Tuberculosis Sanitarium and Department of Surgery, University of Illinois, Chicago, Ill.

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*Special Fellow of the World Health Organization sponsored by the American College of Chest Physicians.

extrafacial planes of dissection over wide expanses of the chest wall. To resect upper ribs, in the face of extrapleural dissection at the apex, would leave little more than shreds of intercostal tissue representing the upper chest wall. Likewise, there is no tissue locally from which to construct a "pleural tent." Even without this set of circumstances, we feel that the added burden of paradoxical motion in the chest wall should be avoided if possible, since it undoubtedly increases the morbidity, particularly when added to an extensive pulmonary resection. Thus, we rarely consider concomitant thoracoplasty.

2. *Postresection Thoracoplasty.*—Since one cannot be positive that a serious space problem will necessarily develop following any given resection, it can be argued that it is reasonable to carry out the indicated resection, however extensive it may be, and hope for full and complete pulmonary expansion. Any space or empyema that may result is then treated by needle aspiration, tube drainage, or thoracoplasty as indicated. This approach has the disadvantage of allowing a complication to develop which might have been prevented.

3. *Preresection Thoracoplasty.*—In advocating a preresection thoracoplasty, we subscribe to the tenet that by careful evaluation the exact extent of the resection to be performed, or at least its maximal and minimal limits, can be clearly determined. The anatomic extent of involvement is estimated by review of all available x-ray films as well as by other methods of examination which include bronchoscopy, bronchography, and laminography.

The lateral laminogram is often particularly helpful in determining whether there may be significant residual disease in the middle lobe or in the superior segments of the lower lobes. Likewise, a great deal may be learned concerning inflammatory changes of the bronchial tree and possible distortions of the spacial relationships between segments and lobes, in these cases, by means of routine bronchography.

Physiologic evaluation, including bronchospirometry as well as determination of pulmonary artery pressures by right heart catheterization, permits a more complete classification of the patient in regard to surgical risk.

We are further influenced by clinical factors, such as the presence of contralateral disease, which might impose limitations on extent of resection on the one hand, or by drug resistance on the part of the organism which might argue for wider resection on the other hand.

Due allowance is made, of course, for the patient whose disease has already so contracted a large extent of lung parenchyma over a chronic course that the volume of lung to be removed is small, in spite of the total number of lung segments involved. Under these circumstances, compensation has already been largely effected for the tissue to be removed and a space-reducing procedure may not be necessary.

After consideration of all these factors, we have adopted the policy of performing a preliminary tailoring thoracoplasty if it is expected that the proposed resection will consist of an amount of lung greater than the volume of one lobe but less than a total pneumonectomy.

TECHNIQUE

Preliminary tailoring thoracoplasty, as we use it, is carried out some 3 or more weeks before the pulmonary resection. It consists of subperiosteal removal of the first rib from the tip of the transverse process to the costochondral junction and of most of the second and third ribs from the tips of the transverse processes to a point anteriorly just short of the costochondral junction.

Our purpose is to shorten the superior inferior axis of the chest, since this appears to be the critical diameter. Consequently, there is no advantage in resecting the second and third ribs beyond the point that is on a horizontal level with the posterior portion of the fourth rib.

Further, an apicolysis may be performed which tends to ensure that the pleural dome is dropped to the level of the fourth rib posteriorly and the stumps of the second and third ribs anteriorly. Even though this level of the pleural dome achieved by apicolysis may not be a permanent one, it appears at times to have the advantage of reducing further the vertical diameter of the hemithorax, particularly in the gutter.

At the subsequent thoracotomy, the chest is entered through the bed of the fifth rib. If added collapse is required, a five-rib thoracoplasty of tailoring type can be had by the resection of an appropriate length of the fourth rib. If this is not necessary, the hemithoracic volume is not affected beyond the original three-rib procedure.

MATERIAL AND RESULTS

In the past 4 years, 31 patients have undergone pulmonary resection of more than one lobe but less than the entire lung, subsequent to a preliminary three-rib tailoring thoracoplasty in this institution. There were no deaths. Two patients incurred pneumothorax at the time of thoracoplasty because of inadvertent entrance into the pleural space. One of these required a short period of water-seal drainage.

The types of subsequent resections carried out are summarized in Table I and, as can be seen, 19 of the 31 patients were left with only basal segments following resection. In 6 patients, the fourth rib was removed in addition to the fifth rib at the time of resection, in order to obtain additional collapse.

TABLE I. TYPE OF RESECTION PERFORMED IN 31 PATIENTS WHO HAD PRERESECTION TAILORING THORACOPLASTY

Left upper lobe and superior division lower lobe	14
Right upper lobe, middle lobe, and superior division lower lobe	5
Right upper lobe and middle lobe	5
Left upper lobe and wedge of lower lobe	5
Right upper and middle lobes and wedge of lower lobe	2
	31

In addition to the larger volume of resected lung, these patients were usually left with raw segmental surfaces. They had, therefore, the two chief predisposing factors to space problems. In spite of this fact, only 2 of the patients developed this complication, an incidence of 6 per cent.

One such patient who had undergone resection of all but the basal segments of the right lower lobe retained a space even though her thoracoplasty was increased to the fifth rib at the time of resection. She required tube drainage for 6 weeks before the space was obliterated. The second patient who had resection of the right upper lobe and superior segment of the lower lobe retained a pleural space which would not further decrease. He developed tuberculous empyema several months postoperatively. Both of these complications seem attributable to the ravaged state of the lung that was left behind. We are convinced that many areas of lung originally affected, even though beautifully cleared by treatment, are reluctant to expand much beyond their accustomed size. This factor, however difficult to define or estimate, is nevertheless very real.

SUMMARY AND CONCLUSION

When, in the management of far-advanced pulmonary tuberculosis by resection, it appears likely that only a small portion of the lung will be left behind, some degree of tailoring of the hemithorax is necessary. In a series of 31 cases, we have anticipated this circumstance by careful preoperative study and have prepared for it by a preresection thoracoplasty. This practice has rewarded us by an incidence of complication far below the expected. The added surgery has likewise caused a low incidence of morbidity.

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AN EVALUATION OF TECHNIQUES OF PULMONARY RESECTION FOR TUBERCULOSIS

David V. Pecora, M.D., Ray Brook, N. Y.

ALTHOUGH pulmonary resection for tuberculosis has been popular for a number of years, opinions vary among surgeons regarding various technical aspects. For instance, Steele[1] found that a considerable proportion of surgeons do not use subsegmental resection or have reservations regarding its use. Some prefer to use lobectomy in preference to smaller resections in patients harboring tubercle bacilli resistant to antituberculosis drugs. A number of writers have discussed the superiority of various types of bronchial closure. Yet, a review of the recent literature fails to yield convincing evidence to support many of the claims which have been made. In order to attempt to answer some of the more important questions which have been raised, the surgical experience at the Ray Brook State Tuberculosis Hospital between January, 1950, and January, 1957, has been reviewed.

TYPE OF RESECTION

It has been stated that the risk of pulmonary resection increases with the amount of tissue removed. Generally, this conclusion seems to be supported by the data in Tables I and II. Included in these tables are only pure procedures, combinations of different procedures at the same operation having been eliminated. Segmental resection, lobectomy, and pneumonectomy were performed by the individual ligation technique. The pleural surfaces were not routinely approximated but care was exercised to control bleeding and air leaks by suture or ligature. Subsegmental resections were performed exactly as segmental resections except that the hilar dissection occurred at the subsegmental level. Wedge resections were performed according to two general techniques, "open" and "closed." The "open" technique (Fig. 1) consisted of progressively cutting and suturing the lung with either interrupted fine silk or continuous atraumatic chromic catgut. The "closed" technique (Fig. 2) consisted of blocking off the lesion with clamps, suturing beneath the clamps, and then amputating the lesion external to the suture line. Again, either interrupted fine silk or continuous atraumatic chromic catgut in two layers were employed.

The wedge-segmental resection consisted of preliminary isolation and division of the segmental vessels and bronchi and development of the intersegmental plane until disease was encountered entering the adjacent segment, followed by

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removal of the remaining diseased tissue by either "open" or "closed" wedge technique. The "closed" type is illustrated in Fig. 3. The wedge-segmental resection has proved extremely useful in conserving functional tissue.

Before the various types of surgery can be compared, it is important to know whether or not they have been performed upon patients harboring culturable tubercle bacilli, as it has been our experience that this affects the incidence of tuberculous complications. This is evident when one compares Table I and Table II. Moreover, in searching for standards for comparison it appears

Fig. 1.—"Open" wedge resection.

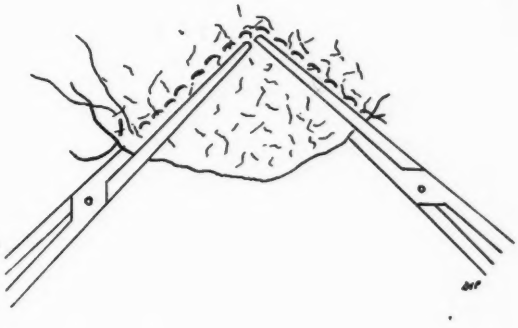

Fig. 2.—"Closed" wedge resection.

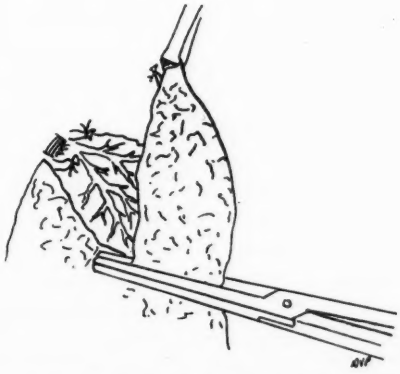

Fig. 3.—"Closed" wedge-segmental resection.

appropriate to employ the postoperative complications and deaths occurring within one month following surgery. Since results were similar employing the "closed" and "open" techniques, no attempt is made to differentiate them.

The incidence of postoperative hemothorax is not related to the size of the resection; this is to be expected since bleeding has usually been found to emanate

TABLE I. TYPE OF RESECTION BY EARLY POSTOPERATIVE COMPLICATIONS—PATIENTS HARBORING CULTURABLE TUBERCLE BACILLI

PROCEDURE	NUMBER	HEMO-THORAX	OPERATIVE SPREAD	BRONCHO-PLEURAL FISTULA OR EMPYEMA	OPERATIVE DEATH
Wedge	37	0	1	3	0
Wedge-segmental	17	0	0	2	0
Subsegment or segment	4	0	0	2	0
Lobectomy	26	0	1	4	0
Pneumonectomy	15	0	0	4	2
Total	99	0	2	15	2

TABLE II. TYPE OF RESECTION BY EARLY POSTOPERATIVE COMPLICATIONS—PATIENTS HARBORING NO CULTURABLE TUBERCLE BACILLI

PROCEDURE	NUMBER	HEMO-THORAX	OPERATIVE SPREAD	BRONCHO-PLEURAL FISTULA OR EMPYEMA	OPERATIVE DEATH
Wedge	178	3	0	1	1
Wedge-segmental	34	2	1	1	0
Subsegment or segment	25	1	0	0	0
Lobectomy	39	0	0	2	0
Pneumonectomy	12	0	0	1	1
Total	288	6	1	5	2

from chest wall vessels. The incidence of operative spread of disease also appears unrelated to the size of the resection. This is also to be expected since this complication appears generally related to factors such as amount of sputum, position of the patient during surgery, conduct of anesthesia, and the speed with which the bronchus leading to the source of sputum is occluded. On the other hand, the incidence of bronchopleural fistula and empyema does appear generally related to the size of resection. This can be explained to a great extent on the basis of the fact that more difficulty is experienced in obliterating the pleural space after larger resections. This is especially so in the pneumonectomy group.

The problem of obliterating residual pleural spaces following pneumonectomy has been simplified by the following practices. After resection the pleural cavity is drained with the aid of an apparatus previously described.[2] Thereafter, until thoracoplasty is performed, approximately 3 weeks later, the pleural cavity is maintained as dry as possible by thoracentesis. After thoracoplasty is performed, any remaining pleural air and fluid is aspirated before the wound is closed. If the pleural cavity contains a considerable amount of clotted exudate, a small incision is made through the bed of a resected rib and the clots removed, care being taken to prevent unnecessary bleeding. If the parietal pleura should prove too rigid to collapse firmly against the mediastinum, it is removed according to the method of Grow.[3]

Although three of the four early deaths followed pneumonectomy, it should be noted that one, a cardiac arrest during surgery, was apparently due to anesthesia difficulties. In one patient a lobectomy was planned but, because of hemorrhage due to laceration of the pulmonary artery, a pneumonectomy was performed. Although the hemorrhage was thus controlled the patient lived only

2 hours postoperatively. This death might well be credited to the lobectomy group. The third patient died 5 days postoperatively of cor pulmonale and pulmonary edema. The fourth patient died of intrapleural hemorrhage following wedge resection. Since bleeding appeared to emanate from the chest wall, this complication could have occurred following any type of resection.

IMPORTANCE OF EXTENT OF DISEASE

Tables III and IV summarize the early complications according to the estimated volume of surgically treated lung involved by disease. It is obvious that the incidence of bronchopleural fistula and empyema correlates even better with the extent of disease than with the type of resection performed. Indeed, this may very well be the principal determining factor in prognosis following various types of resection. It is interesting that the incidence of hemothorax did not correspond to the amount of disease, confirming the impression that this complication is due to the occasional chest wall bleeder which is accidentally overlooked. As in Tables I and II and for similar reasons there appears to be little correlation between extent of disease and incidence of operative spread of disease.

TABLE III. EXTENT OF DISEASE IN THE SURGICALLY TREATED LUNG BY EARLY POSTOPERATIVE COMPLICATIONS—PATIENTS HARBORING CULTURABLE TUBERCLE BACILLI

ESTIMATED VOLUME OF DISEASED LUNG	NUMBER	HEMO-THORAX	OPERATIVE SPREAD	BRONCHO-PLEURAL FISTULA OR EMPYEMA	OPERATIVE DEATH
Less than half	74	0	2	10	0
More than half	25	0	0	5	2
Total	99	0	2	15	2

TABLE IV. EXTENT OF DISEASE IN THE SURGICALLY TREATED LUNG BY EARLY POSTOPERATIVE COMPLICATIONS—PATIENTS HARBORING NO CULTURABLE TUBERCLE BACILLI

ESTIMATED VOLUME OF DISEASED LUNG	NUMBER	HEMO-THORAX	OPERATIVE SPREAD	BRONCHO-PLEURAL FISTULA OR EMPYEMA	OPERATIVE DEATH
Less than half	260	6	1	4	2
More than half	28	0	0	1	0
Total	288	6	1	5	2

TREATMENT OF THE BRONCHUS

In the series of resections other than wedge resections, the proximal end of the divided bronchus was closed with end-on fine silk sutures. Prior to early 1954, the bronchial stump was almost always covered with pleura or pulmonary tissue; since that time the bronchial stump has not been covered except following some pneumonectomies. Allowing for factors such as drug therapy, bacteriology, and extent of disease, it has been impossible to demonstrate a difference in incidence of bronchopleural fistula in the two groups of patients. Moreover, exploration of a number of uninfected pleural air spaces communicating with

the bronchial tree has usually demonstrated these communications to lie on the lung surface and the bronchial stump to be well healed. This has been true even after obviously diseased bronchi have been divided and sutured, provided antituberculous drug therapy has been administered. Generally speaking, the occurrence of pleural empyema seems to precede rather than follow reopening of a sutured bronchus.

PRERESECTION THORACOPLASTY

Most surgeons agree that thoracoplasty may be indicated following resection to obliterate remaining pleural spaces or empyema. However, the place for preresection thoracoplasty is not well defined. Tables V and VI were compiled in an attempt to evaluate preresection thoracoplasty in the light of other important factors which affect early postoperative results. It is to be expected that the incidence of operative spread of disease and postoperative hemothorax would not be affected by preresection thoracoplasty. It is interesting that the incidence of bronchopleural fistula and empyema is higher in patients who have had preresection thoracoplasty. This difference is probably at least partially due to the fact that this group represents patients with the greater amount of disease. However, the results may to some extent indicate the difficulty one experiences in filling the conical apical pleural space which frequently exists following resection under thoracoplasty.

TABLE V. PRERESECTION THORACOPLASTY BY EARLY POSTOPERATIVE COMPLICATIONS—PATIENTS HARBORING CULTURABLE TUBERCLE BACILLI

	NUMBER	HEMOTHORAX	OPERATIVE SPREAD	BRONCHOPLEURAL FISTULA OR EMPYEMA	OPERATIVE DEATH	NUMBER WITH OVER HALF OF OPERATED LUNG DISEASED
No thoracoplasty	74	0	1	8	1	14
Thoracoplasty	25	0	1	7	1	11
Total	99	0	2	15	2	25

TABLE VI. PRERESECTION THORACOPLASTY BY EARLY POSTOPERATIVE COMPLICATIONS—PATIENTS HARBORING NO CULTURABLE TUBERCLE BACILLI

	NUMBER	HEMOTHORAX	OPERATIVE SPREAD	BRONCHOPLEURAL FISTULA OR EMPYEMA	OPERATIVE DEATH	NUMBER WITH OVER HALF OF OPERATED LUNG DISEASED
No thoracoplasty	266	6	1	4	2	18
Thoracoplasty	22	0	0	1	0	10
Total	288	6	1	5	2	28

DISCUSSION

There appears to be little reason to exclude any of the types of pulmonary resection reviewed in this communication from the armamentarium of a surgeon on the assumption that it carries too great a risk. Each technique has its

applications and, if properly used, carries a low morbidity. Indeed, what determines to a great extent the incidence of serious complications and mortality is the extent of disease, which fundamentally affects both the technical difficulties encountered at operation and the physiology of the patient.

There is no evidence that lobectomy is more valuable than any other type of resection in the treatment of patients harboring resistant organisms. What seems important is that the major disease be removed. This may require a wedge resection or a pneumonectomy. Furthermore, any type of resection without antituberculous drug protection should be avoided. If one employs drugs to which the patient's tubercle bacilli are sensitive, the fact that the organisms are resistant to other drugs is unimportant.[4, 5]

Our results with single layer closure of the bronchus have been excellent, indicating that little is to be gained by adopting more elaborate techniques. This assumption seems further supported by the fact that covering the bronchus with pleura or pulmonary tissues has not improved results. Two factors of importance in the prevention of bronchopleural fistula and empyema are early obliteration of pleural air spaces and prolonged antituberculous drug therapy. Bronchial disease, although emphasized by others, does not seem to predispose to the occurrence of bronchopleural fistula to an appreciable extent.

There is no evidence that preresection thoracoplasty is of value. On the contrary, it may predispose to poor results.

SUMMARY

Seven years' experience with various types of resections for pulmonary tuberculosis is reviewed. By judicious use of the procedures described, a maximum amount of functional lung tissue can be preserved. The postoperative results are determined to a great extent by the amount of disease present. There is no evidence that lobectomy is superior to any other procedure in the treatment of patients with resistant organisms. Bronchial disease is of little importance provided adequate antituberculous drug therapy is available. The simplest bronchial closure yields excellent results. There is no evidence that preresection thoracoplasty is of value.

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PULMONARY ABSCESS: A STUDY OF 70 CASES

Daniel N. Pickar, M.D., and William F. Ruoff, M.D.,** Louisville, Ky.*

PULMONARY abscess has long been recognized as one of the most serious diseases of the lungs and, prior to the availability of the antimicrobial agents, the prognosis was extremely poor, both as to morbidity and mortality.[1, 2] With the advent of the sulfonamides, penicillin, and the other antimicrobial agents, and with the development of better techniques in the field of pulmonary surgery, the prognosis for these cases has greatly improved.[3, 4]

It is the purpose of this paper to present a study of 70 consecutive cases of pulmonary abscess treated at the VA Hospital, Louisville, Ky., during the past 10 years. Abscesses resulting from tuberculosis, fungus, parasitic infection, and carcinoma constitute special categories and were purposely omitted from this study.

METHODS AND MATERIALS

All cases of pulmonary abscess in this series were referred to the Chest Therapy Board for evaluation and recommendations as to treatment. The Board consists of the Chief of the Section on Chest Diseases, the Chief of the Radiology Service, the Consultant in Chest Diseases, and the Consultant in Thoracic Surgery. The initial plan of management was to place the patient on bed rest and, after sputum specimens had been collected for culture, an antimicrobial agent was started. It was the preference of the Medical Service to start the patients on penicillin alone, usually in a dosage of 100,000 units of crystalline penicillin every 3 hours or 600,000 units of procaine penicillin twice daily. This was not a fixed policy, however, and the responsible physician could use any antibiotic, alone or in combination, which he felt desirable, particularly if the patient had received antibiotic therapy prior to admission. Subsequent antibiotic therapy was dictated by the clinical response and the results of bacteriologic determinations, including sensitivity studies. Auxiliary supportive measures which were employed as indicated were postural drainage,

From the Medical Service, Veterans Administration Hospital, Louisville, Ky., and the Department of Medicine, University of Louisville School of Medicine.

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*Chief of the Section on Chest Diseases, VA Hospital, and Assistant Professor of Medicine, University of Louisville School of Medicine.

**Resident in Medicine, VA Hospital, Louisville, Ky.

bronchodilator drugs, expectorants, blood tranfusions, and a nutritious diet. Necessary procedures for the recognition and amelioration of co-existing pulmonary and systemic diseases were carried out.

The response of the abscess to medical treatment determined whether or not surgical treatment was indicated. In general, surgery was felt to be indicated if the abscess persisted or if carcinoma was suspected.

RESULTS OF STUDY

Race, Age, and Sex.—

Of the 70 patients with pulmonary abscess, 59 were white and 11 were Negro. There was a uniform distribution in each 10-year period from 20 to 60 years of age. Only 5.7 per cent of the patients were beyond 60 years of age. All patients were males.

Symptoms.—

The duration of symptoms prior to admission varied from one month or less up to 26 months. Thirty patients (42.8 per cent) had had symptoms one month or less. Fifty-six patients (80 per cent) had had symptoms 5 months or less. Five patients (7.2 per cent) had had no symptoms prior to admission. Three of these 5 developed abscesses after admission to this hospital.

Table I shows the incidence of symptoms in the 70 patients.

TABLE I. INCIDENCE OF SYMPTOMS

Cough	(61)	87.2%	Weakness	(9)	12.8%
Purulent sputum	(52)	74.2%	Malaise	(8)	11.4%
Chest pain	(36)	51.4%	Anorexia	(7)	10.0%
Hemoptysis	(32)	45.7%	Joint distress	(4)	5.8%
Weight loss	(25)	35.7%	Headache	(3)	4.3%
Fever	(25)	35.7%	Dyspnea	(2)	2.8%
Chills	(16)	22.9%	Abdominal pain	(2)	2.8%
Night sweats	(11)	15.8%	Stiff neck	(1)	1.4%

Pre-Existing or Co-Existing Disorders.—

Nonpulmonary disorders: Seven patients had severe oral sepsis, 5 had diabetes mellitus, 4 were chronic alcoholics, 3 had neurological disease, and 2 had cerebral arterial thrombosis. Fifteen patients had one each of the following disorders: post-tonsillectomy, thrombophlebitis, dorsal kyphosis, arteriosclerotic cardiovascular disease, old chest injury, upper gastrointestinal hemorrhage of unknown cause, anxiety reaction, chronic pancreatitis, periarteritis nodosa, syphilis, lymphatic leukemia, cirrhosis, fracture, malnutrition, and coronary insufficiency.

Pulmonary disorders: Table II shows the incidence of pre-existing or co-existing pulmonary disorders.

In the 2 cases of bronchial obstruction, one was due to a narrowed bronchus from an unknown cause, and the other was caused by a rupture of a calcified lymph node through the bronchial wall.

Laboratory Studies.—

Initial white blood count: Twenty-four patients (34 per cent) had a total white count of 5,000 to 10,000 per cubic millimeter. In the 10,000 to 15,000

TABLE II. PULMONARY DISORDERS

Pneumonia	11
Pulmonary emphysema	6
Recurrent abscesses	3
Bronchiectasis	2
Bronchial obstruction	2
History of pneumonia and previous lung abscesses	1
Anomalous bronchi	1
Pulmonary infarct	1

range were 20 patients (28.9 per cent). In the 15,000 to 30,000 range were 25 patients (35.7 per cent). The patient with lymphatic leukemia had a total count of 495,000 white cells per cubic millimeter.

In the differential, there was a definite shift to the left with 85 per cent of the patients showing more than 60 per cent granulocytes.

Anemia: Twenty patients (28.6 per cent) had hemoglobin levels under 12 Gm., red blood cell counts under 4,000,000, and/or a hematocrit under 40 per cent.

Bacteriologic studies: Table III represents a composite in each case of one or more cultural studies for the predominating organism. Verification was also obtained in most of the surgically treated abscesses by a direct study of the resected abscess.

TABLE III. BACTERIOLOGIC STUDIES

Streptococcus	(48)	68.6%
Diplococcus pneumonia	(5)	7.1%
Friedländer's bacillus	(4)	5.7%
Hemolytic *Staph. aureus*	(3)	4.3%
Streptococcus plus Friedländer's bacillus	(2)	2.9%
Inconclusively demonstrated	(8)	11.4%
Totals	70	100.0%

Location of Abscesses.—

Table IV shows the location of the abscesses.

TABLE IV. LOCATION OF THE ABSCESS

Right upper lobe	(23)	32.9%	
Right middle lobe	(3)	4.3%	
Right lower lobe	(15)	21.4%	
Total	41		58.6%
Left upper lobe	(10)	14.3%	
Lingula	(4)	5.7%	
Left lower lobe	(10)	14.3%	
Entire left lung	(1)	1.4%	
Total	25		35.7%
Bilateral	4		5.7%
Totals	70		100.0%

Cavity Size.—

In 41 patients (58.6 per cent), the abscesses were 4 cm. or less in the greatest diameter. In 23 patients (33.0 per cent), the abscesses were 4 to 8 cm.

in the greatest diameter and, in 6 patients (8.4 per cent), the abscesses were 8 to 13 cm. in diameter.

Bronchography.—

Bronchograms were performed on 12 patients (17.4 per cent) during their hospitalization. Of these, four were normal and three showed bronchiectasis. In 2 patients, the studies aided in the delineation of the abscess. The procedure was unsatisfactory in 3 patients.

Bronchoscopic Examination.—

Forty-three patients were examined bronchoscopically. Of these, 29 were normal, 2 revealed bronchial stenosis, and 12 showed edema, purulent secretions, or blood from the affected bronchi.

Fever.—

The maximum temperature on the day of admission was normal in 12 patients (17.1 per cent), 99° F. to 101° F. in 41 patients (58.6 per cent), and 101° F. to 104° F. in 17 patients (24.2 per cent).

The duration of fever was 3 weeks or less in 41 patients (58.6 per cent). Twelve patients (17.1 per cent) had no fever. Four patients had a persistent temperature elevation throughout their hospitalization. Of this latter group, 3 died and one left the hospital against medical advice. The remaining 13 patients had a temperature elevation which subsided 2 to 9 weeks after their hospital admission.

Cavity Closure.—

Thirty-five of the 70 patients were considered to have closed cavities within a period of 10 to 120 days. The remaining 35 cavities did not close. Of this group, 24 of the patients were operated upon; 5 died, 4 left the hospital against medical advice, and 2 were discharged from the hospital because they wished to continue therapy under their private physician.

Medical Therapy.—

Forty-four patients were treated medically. As soon as the abscess was diagnosed, sputum was submitted to the laboratory for smear and culture for predominating organisms and sensitivity determinations. An antibiotic was commenced immediately without awaiting the results of the above studies. The choice of an initial antibiotic varied and the selection was influenced by the preference of the ward physician and the consultant staff. In 21 patients, penicillin was used alone; in 12, penicillin plus a tetracycline drug was administered; in 3 patients, penicillin plus streptomycin was used; and in one patient a tetracycline drug alone was used. In another single instance, because of the consideration of possible tuberculosis, streptomycin plus isonicotinic acid hydrazide was given.

It was in the patients with Friedländer's and staphylococcus infections that the sensitivity studies proved to be most helpful in the choice of an effective antibiotic. There were 4 such patients in whom penicillin and/or a tetracycline drug was initially used, and later a tetracycline drug plus chloromycetin, or chloromycetin alone was used.

It is interesting that 3 patients effected a complete recovery without any antibiotic therapy. Of these, 2 had abscesses which closed during a brief observation period and the other refused any antibiotic therapy.

Cause of death in 5 patients treated medically: Patient G. J. E., a 45-year-old white man, died 7 days after admission. He had a severe Laennec's cirrhosis in addition to his pulmonary abscess.

Patient E. E. E., a 36-year-old white man, was admitted to the hospital with periarteritis nodosa. His death resulted from a terminal Friedländer's pneumonia and multiple Friedländer's abscesses in the lung 17 months after admission.

Patient S. R., a 56-year-old white man, was hospitalized for pulmonary abscess for 42 days. Terminally, he had a bronchopneumonia.

Patient F. L., a 72-year-old white man, had completely recovered from his pulmonary abscess, but died from an acute coronary occlusion when he was being discharged from the hospital.

Patient B. W., a 43-year-old white man, had fully recovered from multiple Friedländer's abscesses treated 10 months previously. On his readmission, he again had Friedländer's pneumonia and abscesses. He had had diabetes mellitus for many years. On his final admission, he had a Friedländer's septicemia and a severe jaundice, the cause of which was not determined. He died 15 days after this second admission.

Surgical Therapy.—

It was our policy that medical therapy be given to the patient with an uncomplicated case to the point where no further improvement was considered probable. When carcinoma was suspected, or when surgical complications existed, surgery was advised earlier. Table V shows the reasons for surgery in the 26 cases in which surgery was performed.

TABLE V. REASONS FOR SURGERY

Persistence of abscess and infiltrate on medical therapy	18
Suspected carcinoma	5
Bronchiectasis	1
Abscess rupture through the diaphragm	1
Continuation of open thoracotomy instituted in another hospital	1
Total	26

In reviewing the patients who had an operation, 19 (73 per cent) had had less than 5 weeks of medical therapy. We are of the opinion, after review of the cases individually and applying our present-day criteria for surgical consideration, that 8 of these patients would now be given a longer trial at medical therapy prior to surgery.

Type of surgery performed: The type of surgery performed is shown on Table VI.

Causes of death in surgically treated patients: Patient P. O., a 56-year-old man, had a segmental resection of the RUL and RML and had repeated complications, including empyema and bronchocutaneous fistula, following the initial surgery. Many subsequent surgical procedures were performed. He died 17 months after the initial surgery from pulmonary hemorrhage.

TABLE VI. TYPE OF SURGERY PERFORMED

Right Lung		
Right pneumonectomy	2	
RUL lobectomy	4	
RUL and RML lobectomies	2	
RLL lobectomy	3	
RUL lobectomy and additional segmentectomies	1	
Multiple segmentectomy of one or two lobes	3	
Total		15
Left Lung		
Left pneumonectomy	2	
LUL lobectomy	2	
LLL lobectomy	1	
LUL lobectomy and segment LLL	1	
LUL wedge resection	1	
LUL and LLL wedge and segmentectomy	1	
LLL segmentectomy	1	
Total		9
Thoracoabdominal exploration		1
Open thoracotomy		1
		26

Patient S. H., a 60-year-old man, had chronic lymphatic leukemia which was the major factor in his death 5½ months after admission. He had had an open thoracotomy for a persistent abscess.

Patient R. B., a 29-year-old man, had a left pneumonectomy and died 3 hours postoperatively from shock and acute pulmonary edema.

Patient G. J. B., a 36-year-old man, was admitted with a pulmonary abscess which had ruptured through the diaphragm. This required immediate exploration. He died 84 days after admission from a brain abscess, peritonitis, and generalized sepsis.

Patient P. C., a 40-year-old man, had a right pneumonectomy and died from cardiac standstill during surgery.

Patient M. H. J., a 28-year-old man, had a right pneumonectomy and died 3 hours postoperatively from acute pulmonary edema.

Patient C. J. A., a 43-year-old man, had a right upper lobe and a right middle lobe lobectomy and died 22 days postoperatively from persistent sepsis and acute degeneration of the liver.

Duration of Hospitalization.—

TABLE VII. DURATION OF HOSPITALIZATION

	SURGICAL	MEDICAL
1 month or less	1	7
1-2 months	3	13
2-3 months	5	12
3-4 months	7	8
4-5 months	4	3
5-6 months	3	0
6-7 months	0	0
7-8 months	1	1
Longer than 8 months	2	0
Totals	26	44

Total Duration of Morbidity.—

In determining the duration of morbidity we have included the period of time from the onset of the first distressing symptom to the date of admission to the hospital, the period of hospitalization, and the post-discharge period that was required for additional convalescence up to the time the patient was able to return to work.

The following Table VIII shows the total duration of morbidity.

TABLE VIII. DURATION OF MORBIDITY

	SURGICAL	MEDICAL
1 month or less	0	2
1-2 months	0	5
2-3 months	1	10
3-4 months	6	10
4-5 months	2	9
5-6 months	5	1
6-7 months	5	1
7-8 months	1	1
8-9 months	2	3
9-10 months	1	2
10 months or more	3	0
Totals	26	44

In general, the surgically treated patients had a longer period of morbidity than did the medically treated group. In this connection, it should be recalled that patients requiring surgery were, as a group, more seriously afflicted and, in most cases had had a course of medical therapy which had proved inadequate.

DISCUSSION

The proper use of antibiotics is essential to the effective management of pulmonary abscess. Our studies emphasize the need for identification of the offending organism at the onset of therapy and the need for subsequent studies of the sputum, preferably at weekly intervals, to detect the development of bacterial strains that are resistant to the antibiotic being employed. In our series, there were 4 patients whose original cultures grew Friedländer's bacilli. These organisms were not sensitive to penicillin. There were 2 patients in whom the initial cultures revealed both a streptococcus and Friedländer's bacilli and, with subsequent cultures, sensitivity determinations and clinical correlation, the Friedländer's bacillus was felt to be the offending organism. In 3 patients, hemolytic *Staphylococcus aureus* was not isolated initially but was subsequently cultured. This organism was resistant to penicillin. In all of the above cases, the employment of an antibiotic to which the organism was sensitive was of vital importance.

The selection of patients for surgery is an individual problem. We consider the indication for surgery to be the conclusive demonstration that medical therapy has failed. During the past few years, we have applied this criterion more vigorously than we did during the first part of the study. Our studies reveal that in some patients we performed operation after a brief period of medical therapy and in others while they were still showing some improvement.

We now believe that medical therapy of only 1 to 2 weeks is inadequate, and that if any degree of improvement can be demonstrated medical therapy should be continued. In addition, we believe that operation should be performed if the presence of carcinoma is suspected or if there exist or develop complications which are considered to be surgical such as rupture of the abscess, empyema, bronchiectasis, or bronchostenosis.

It is to be noted that 3 of the 4 patients who had a pneumonectomy died during surgery or in the immediate postoperative period. It has been stressed by other workers[4, 5] that this procedure for pulmonary abscess carries with it a high incidence of complications and a high mortality rate.

The use of antibiotics and the development of better anesthesia and surgical techniques have substantially improved the prognosis in pulmonary abscess. However, it still remains a serious problem. In our series, approximately 70 per cent of the patients required hospitalization of from 1 to 4 months. In 20 per cent, it exceeded 5 months. In 17.1 per cent, the disease terminated in death. Thus, in spite of medical progress, pulmonary abscess continues to be a prolonged morbid process with a substantial mortality rate.

SUMMARY AND CONCLUSIONS

Seventy cases of pulmonary abscess treated at the VA Hospital, Louisville, Ky., have been reviewed. Forty-four of these were treated medically and 26 surgically. There were 12 deaths, representing a mortality of 17.1 per cent.

We consider pulmonary abscess to be primarily a medical problem. Surgery should be performed, however, if continued radiologic and clinical improvement under medical therapy cannot be demonstrated, if carcinoma is suspected, or if complications exist or develop which are considered surgical.

Cultures of the sputum, including sensitivity studies of the organisms, should be made immediately. These studies should be repeated at weekly intervals in order to be certain of the antibiotic sensitivity of the offending organism. This is particularly true in cases in which the infection is caused by *Staphylococcus aureus* or Friedländer's bacilli.

Although the prognosis in pulmonary abscess has improved with the advent of antibiotics and the development of improved anesthesia and surgical techniques, it continues to be a prolonged morbid process with a substantial mortality rate.

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ANOMALOUS SPLITTING OF THE UPPER LOBE BRONCHUS IN RIGHT AND LEFT LUNGS: WITH A NOTE ON THE INCIDENCE IN THE LONDON AREA OF LEFT MEDIAL BASAL SEGMENTS*

E. A. Boyden, Ph.D. (Med.Sc.), Seattle, Wash., and
D. H. Tompsett, Ph.D., London, England

IN THE MUSEUM of the Royal College of Surgeons in London there are some twenty preparations of human lungs in which the whole tracheobronchial tree (and frequently the pulmonary vessels) have been injected by the superb Marco resin technique devised by Dr. D. H. Tompsett.[10] Because of the number and perfection of these casts of distended lungs, the collection provides an unusual opportunity to study variations in the patterns of the bronchopulmonary segments.

Recently, while in residence at the College, the senior author took time to make such a study and found, to his surprise, four pairs of lungs in which there were two upper lobe stems originating from either the right or left main bronchus—two on the left side and two on the right. These had been noted by Dr. Tompsett but not hitherto described. Moreover, the few cases which have appeared in the literature have been based largely on bronchograms. For these reasons, it has seemed desirable to place these cases on record.

CASTS OF RIGHT UPPER LOBE

Figs. 1 and 2 are sketches of the segmental bronchi of two right lungs. That of Fig. 1 shows two upper lobe stems arising in close proximity and having a combined area of origin 1.6 cm. in length. The second sketch (Fig. 2), drawn from the posterior side, shows two upper lobe stems which are further apart. The length of the combined area of origin in this cast is 2.4 cm. In each case the higher of the two bronchi supplies the zone of the right apical segment; the lower one the territories of the anterior and posterior segments. Foster-Carter,[6] in his Fig. 20A, reproduces a bronchogram which seems to resemble closely the specimen shown in our Fig. 2. Incidentally, Fig. 2 displays another anomaly—namely, dual origin of the branches of the superior (subapical) segment (Boyden,[2] Fig. 72).

From the Departments of Anatomy, University of Washington, Seattle, Wash., and Royal College of Surgeons of England, London, England.

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*Text and drawings by the senior author.

A somewhat different pattern has been published by Brock[3] who injected the upper of two upper lobe bronchi in an anatomical specimen. In this case, the two bronchi had approximately the same position as those in Fig. 2 (his Fig. 128), but the upper one was distributed to only the mediastinal portion of the apex and not to the whole of the zone comprising the apical segment—an area corresponding to that supplied by the first branch of the left main bronchus in Fig. 4.

From specimens of this kind, it is but a short step to rarer cases in which a ramus of the upper lobe originates at the junction of the trachea and the right upper lobe bronchus (cf. Boyden,[2] Fig. 31) and even to rami which are frankly tracheal in origin. One of the most interesting of these is being prepared for publication by Dr. David Browne[4] of Charing Cross Hospital, London.

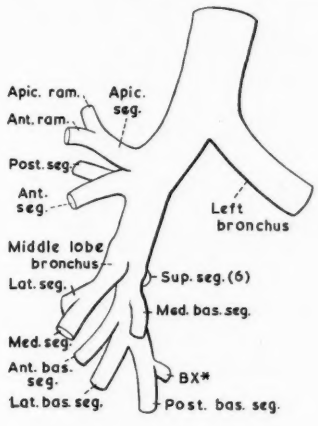

Fig. 1.

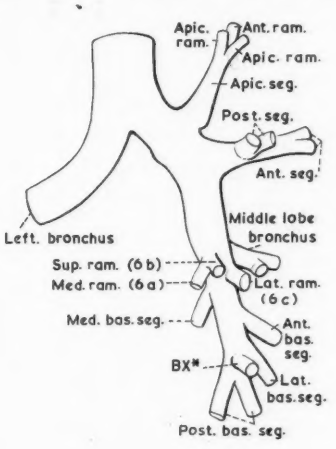

Fig. 2.

Fig. 1.—Anterior view of right bronchial tree of Cast *M1001* in Royal College of Surgeons which illustrates first stage in cleavage of the right upper lobe bronchus.

Fig. 2.—Posterior view of right bronchial tree of Cast *M1005* which shows separation of two components of right upper lobe bronchus. Both Figs. 1 and 2 are from lungs of adults.

This cast has two upper lobe stems, one at the usual site (an inch above the middle lobe bronchus) and the other originating from the right lateral side of the lower trachea, almost an inch above the bifurcation. This lobe is cleft by the azygos vein.

CASTS OF LEFT UPPER LOBE

The 2 cases presented here resemble those of the right side in having the two upper lobe bronchi closely adjacent to each other. In the first one (Fig. 3), the higher of the two bronchi supplies the apical-posterior segment. The lower of the two divides almost immediately into a bronchus which supplies the anterior and lingular segments and into a lower lobe bronchus. In the book by Huizinga and Smelt[7] (their Fig. 20), there is a bronchogram of an adult patient that closely resembles that from the 15-day-old infant shown in Fig. 3.

In the second case (Fig. 4), the left main bronchus, at the usual site of bifurcation, gives rise first to a small split-off portion of the apical bronchus, then divides immediately into upper and lower lobe bronchi. Apparently, such a "splinter" bronchus is much less common on the left than on the right main bronchus.

These 2 cases are to be distinguished from a left eparterial bronchus which originates much higher up on the main bronchus. (For description of 5 such cases, see Boyden,[2] p. 217.)

THE INCIDENCE OF SEPARATE LEFT MEDIAL BASAL BRONCHI

One of the striking variations in the bronchial tree of the left lower lobe is the separate origin of the medial basal bronchus (see pink-colored bronchus, Fig. 4). Because of this aberration, the left medial basal segment was recognized as such at the last International Congress of Anatomists in Paris, 1955;

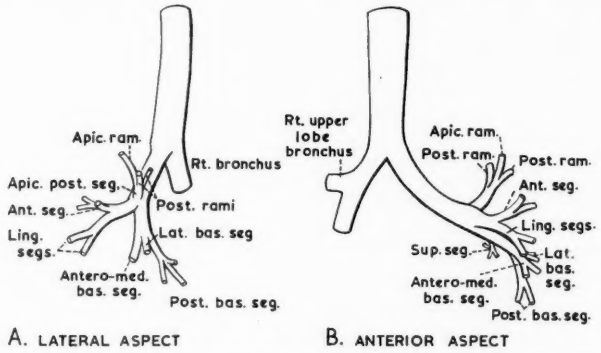

Fig. 3.—Drawings of left bronchial tree of Cast *S.254 1* from an infant 15 days old. Note separation of left upper lobe into apical-posterior and anterior-lingular components, with the former as the first branch of the left main bronchus.

and for this and other reasons (Boyden,[2] p. 30), it is believed that the so-called anterobasal segment of the London Congress of 1949 should at least be designated by the name anteromedial basal segment, as originally proposed by Jackson and Huber[8] in 1943.

This medial basal segment was first described by Dévé[5] in 1900. In 1949, Berg, Boyden, and Smith[1] reported its separate occurrence in 10 per cent of 60 lungs of people that had been residents of Minnesota. Four years later, Pitel and Boyden[9] reported it as occurring in 4 per cent of an additional 50 lungs from the same locality. The incidence in 110 individuals was thus 7.3 per cent. Strangely enough, 7 cases of this occur in the 21 injected specimens prepared up to this time by Dr. Tompsett at the Royal College. Subsequently, it was ascertained that Dr. David Browne[4] at Charing Cross Hospital has the same number of cases in approximately the same number of injected specimens. Therefore, the incidence of a displaced left medial basal bronchus in two London

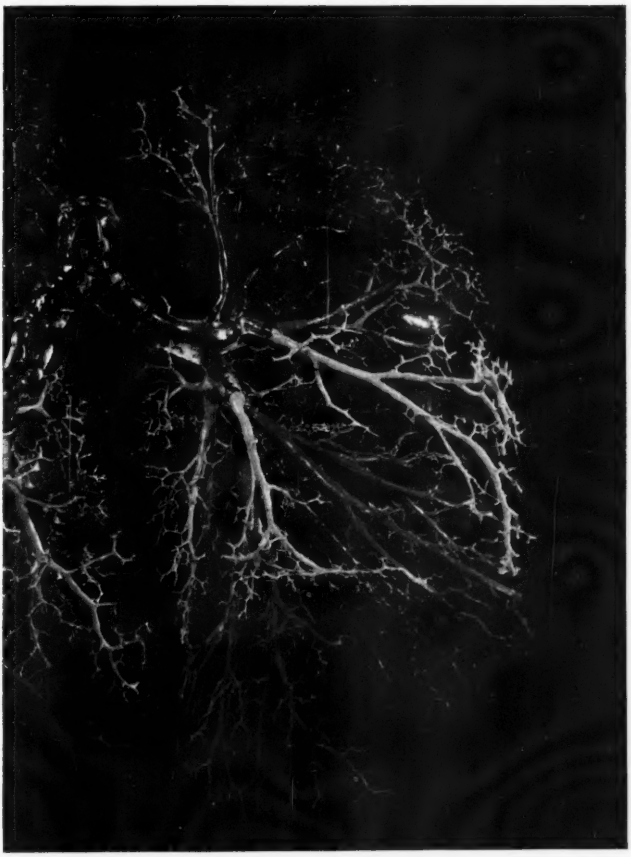

Fig. 4.—Color photograph of left bronchial tree of Cast *M1004* in Royal College of Surgeons. Note first (uncolored) branch of left main bronchus, representing separately arising mediastinal ramus of apical-posterior bronchus (elements of B^1a and B^1b).

Upper lobe bronchi: *red*, larger portion of apical-posterior stem (Boyden's $B^1 + {}^3a$); *dark blue*, rest of stem (Boyden's B^3b); *dark green* (barely visible in color reproduction), anterior bronchus (Boyden's B^2); *gray*, superior lingular bronchus (B^4); *pink*, inferior lingular bronchus (B^5).

Lower lobe bronchi: *yellow*, superior (apical) bronchus (B^6); *pink*, medial basal (B^7); *blue*, anterior basal (B^8); *red*, lateral basal (B^9); *green*, posterior basal (B^{10}). For reproduction of the whole tree of this specimen see Fig. 38, Tompsett.[10]

museums is about 33 per cent. It would seem that this high incidence in independent collections could not be explained on the basis of small samples. Therefore, it is suggested that these figures must point to either the existence of a special strain in the population or to some environmental factor which produces this aberration.

SUMMARY

Four cases of cleft upper lobe bronchi, as revealed by casts of the tracheobronchial tree, are described. Two of these occurred in the right lung and two in the left. In addition, a rather unexpected incidence of left medial basal segments, arising separately from the bronchial tree, is reported. This anomaly was found in 33 per cent of approximately 40 casts made independently in two London museums, as contrasted with an incidence of 7.3 per cent in 110 anatomical specimens dissected in the state of Minnesota. Some interpretation other than that of small sampling would seem to be required to explain these facts.

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ENDOMETRIOSIS INVOLVING THE PLEURA

Charles B. Ripstein, M.D., Michael Rohman, M.D., and Jacques B. Wallach, M.D., New York, N. Y.*

INTRODUCTION

INVOLVEMENT of the pleura by endometriosis is rare, 2 cases having been reported in the literature. The following report illustrates the diagnostic and therapeutic problems encountered in this lesion.

CASE REPORT

J. W., a 24-year-old Negro nulliparous housewife, was admitted to the Bronx Municipal Hospital Center on Oct. 11, 1957, for diagnosis and treatment of a right pleural effusion. Six months prior to admission a dull right-sided chest discomfort was noted which gradually increased in intensity to a sharp "sticking" pain of severe degree, aggravated by coughing and deep respirations. Five months prior to admission, a cough developed and persisted, productive of ¼ to ½ cup of white sputum daily. A recurrent feverish sensation was noted in the afternoons. During this period, there was a fifteen pound weight loss associated with anorexia, general malaise, and easy fatigability. There had been no previous known contact with tuberculosis. Hemoptysis, wheezing, chest trauma, and foul sputum were denied. X-ray studies revealed a right pleural effusion and the patient was admitted with the diagnosis of suspected pulmonary tuberculosis.

Menarche had occurred at 14 years of age with menses appearing every 28 days and lasting from 4 to 7 days. In recent years, the amount of bleeding had increased and the early part of the menses was accompanied by moderate abdominal pain. The patient had married 4 years previously. Although no contraceptives were employed, conception had not occurred.

Physical examination revealed a well-developed and well-nourished Negro female, appearing chronically ill, with mild exertional dyspnea. Temperature was 100.6° F., pulse rate 82 per minute, respiration 28 per minute, blood pressure 110/70 mm. Hg. The positive findings were limited to the chest and pelvis. There was a definite respiratory lag with decreased expansion of the right hemithorax. The left lung was clear to percussion and auscultation, except for a few basilar rhonchi which cleared on coughing. On the right side, there were decreased-to-absent breath sounds over the lower three fourths of the chest posteriorly, dullness to percussion over this area, and fine râles above the level of dullness. Pelvic examination revealed a marital introitus and irregularity of the posterior vaginal wall with slight guarding and deep tenderness in the para-uterine area. Except for mild anemia (hemoglobin 11.0 grams per cent), the laboratory studies on this and subsequent admissions were within

From the Departments of Thoracic Surgery and Pathology, The Bronx Municipal Hospital Center, The Albert Einstein College of Medicine, New York, N. Y.

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*Fellow of the American Trudeau Society, Medical Section of the National Tuberculosis Association.

normal limits. Repeated sputum examinations for acid-fast bacilli were negative on smear and culture. Tuberculin skin testing with OT 1:10,000 and 1:1,000 was slightly positive. Skin tests for histoplasmosis and coccidiomycosis were negative.

On the day of admission, 1,400 c.c. of thin, bloody, nonclotting fluid was removed from the right pleural cavity. The fluid had a total protein of 6.5 mg. per cent, 590,000 red cells per cubic millimeter, and a hemoglobin of 2.4 grams per cent. Cultures from this, as well as from all subsequent thoracenteses, were negative for pathogens, including acid-fast bacilli. No malignant cells were seen on cytologic examination. Needle biopsy of the pleura was negative for tumor or tubercles.

X-ray studies, which on admission revealed an extensive right-sided pleural effusion and moderate displacement of the heart to the left (Fig. 1), showed no evidence of underlying parenchymal disease following thoracentesis.

The removal of the pleural fluid afforded relief of exertional dyspnea, but this recurred as the fluid rapidly reaccumulated and 11 days later repeated thoracentesis yielded 900 c.c. of similar fluid. The redevelopment of hemorrhagic pleural effusion throughout the 10 months of observation at this institution was a serious problem, necessitating a total of five thoracenteses. The accumulation of fluid and concomitant chest pain could not be related to the menstrual cycle.

Tomographic and fluoroscopic studies demonstrated poor delineation and irregularity of the right diaphragm with diminished excursions, suggesting the possibility of neoplasm of the diaphragm or pleura in this region. A diagnostic pneumoperitoneum was induced and radiographic studies demonstrated thickening of the right diaphragm with irregularity and scalloping (Fig. 2). Films taken the next day demonstrated a right hydropneumothorax and partial collapse of the right lung (Fig. 3). The passage of air from the peritoneal cavity to the right pleural space was of considerable interest as it demonstrated the presence of a definite communication between these sites. There was no evidence of such a communication with the left pleural space.

In view of the failure to obtain a definitive diagnosis, an open right thoracotomy was performed on Nov. 8, 1957. Two small cystic structures were loosely attached to the parietal pleura, one at the level of the fifth rib posteriorly, and the second on the dome of the diaphragm. One of the cysts was opened and contained a small amount of chocolate-colored material. There were numerous yellow-pink, slightly raised and irregular plaques on the parietal pleura, and these became most numerous and confluent over the surface of the diaphragm. The visceral pleura was unremarkable. The diaphragm was opened and no disease was demonstrated in the muscular portion or on the inferior surface. The liver and gall bladder were negative. Abdominal masses could not be palpated and there was no fluid in the peritoneal cavity. Both cysts were removed with an attached portion of parietal pleura. Postoperatively, a small amount of fluid reaccumulated in the chest, but this stabilized and the patient was discharged on Dec. 11, 1957, upon her own request.

The gross specimen consisted of two oval cystic structures which measured 1.5 and 2.3 cm. in greatest diameter. The external aspect of each was smooth and gray white, with a resilient, gray-white wall 1 to 2 mm. in thickness. The inner lining of each cyst was smooth and shiny and the lumina contained bloody serous fluid. One of the structures was attached to a flattened portion of smooth, gray-white pleura which averaged 2 mm. in thickness and measured 2 cm. in greatest dimension. The microscopic diagnosis was "cysts lined by dense fibrous tissue showing frequent hemosiderin-laden phagocytes, suggesting organizing hemorrhage. The possibility of endometriosis cannot be ruled out" (Figs. 4 and 5).

The patient was readmitted on March 31, 1958, when progressively severe exertional dyspnea was noted and x-ray studies revealed further increase of the right pleural effusion. Thoracentesis yielded 1,200 c.c. of thin, bloody, nonclotting fluid.

Because of the diagnosis of possible endometriosis of the pleura, gynecologic consultation was obtained. The uterus was slightly enlarged, irregular, and in almost third degree retroversion. A 3 by 3 cm. nodule projected from the right side of the uterus and a firm

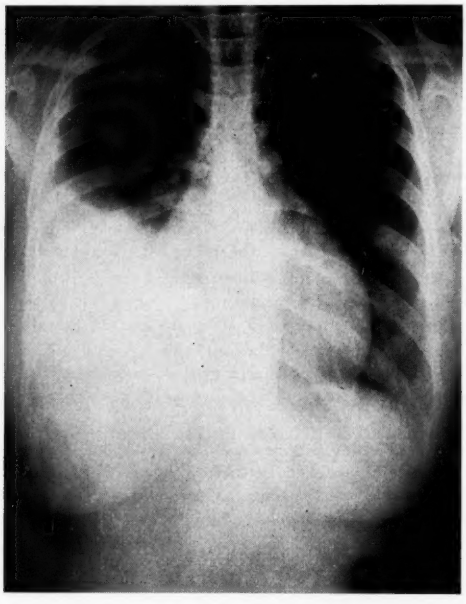


Fig. 1.—Roentgenogram at the time of admission showing right pleural effusion.

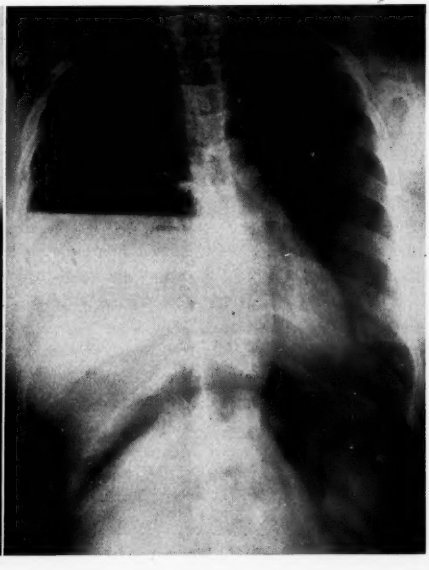


Fig. 2. Fig. 3.

Fig. 2.—Roentgenogram following pneumoperitoneum showing irregular thickening and scalloping of the diaphragm.

Fig. 3.—Roentgenogram after institution of the pneumoperitoneum showing the hydropneumothorax.

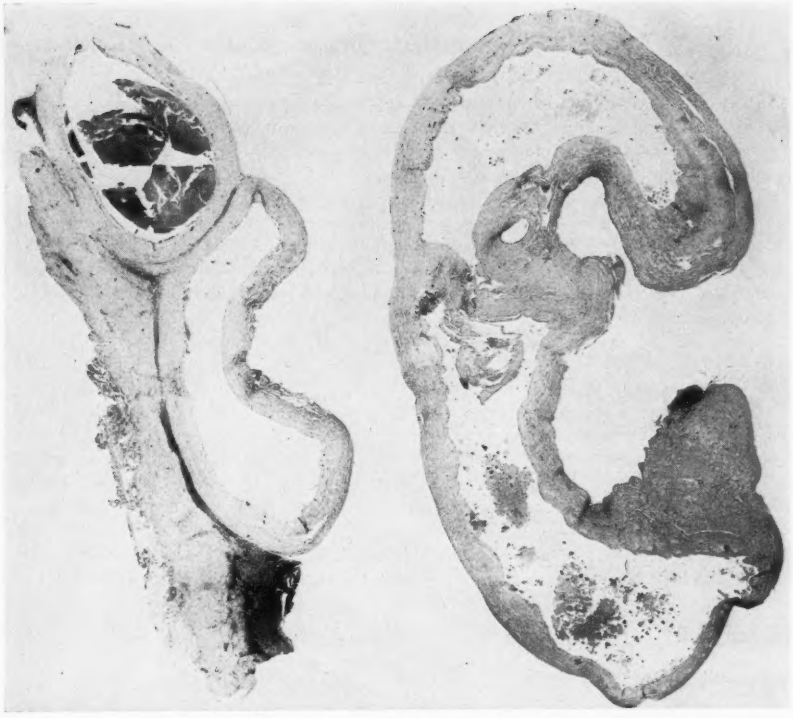


Fig. 4.—Biopsy of pleura and attached cysts with contained blood. (Hematoxylin and eosin; ×7; reduced 1/10.)

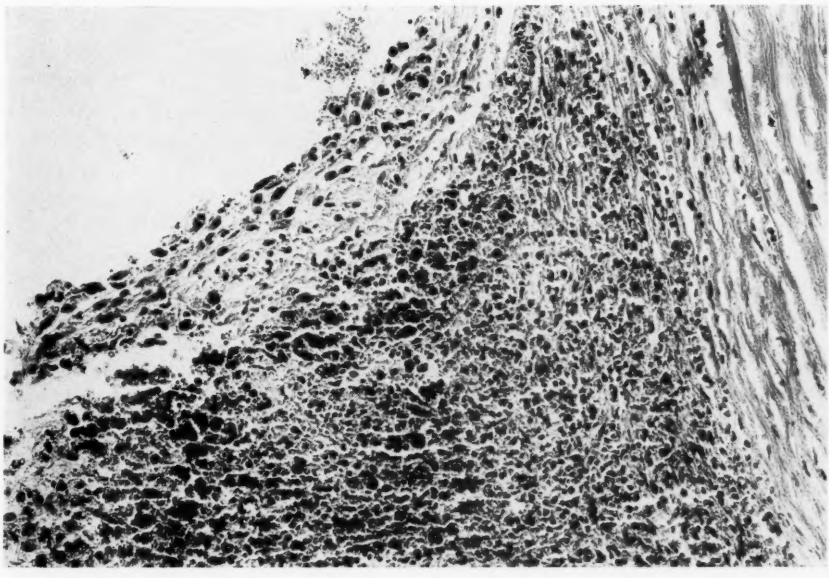


Fig. 5.—Higher magnification of Fig. 4 showing fibrous wall lined by vascular stroma containing abundant pigment-laden macrophages and few epithelial cells of endometrium. (Hematoxylin and eosin; ×250; reduced 1/5.)

6 by 4 cm. nodule was palpated on the left, apparently in the broad ligament. There was nodularity and tenderness in the cul-de-sac. A hysterogram demonstrated a filling defect in the posterior wall of the uterus; the fallopian tubes appeared normal. Culdoscopy was incomplete due to obliteration of the cul-de-sac.

The patient was discharged on May 15, 1958, and readmitted for the third time on June 1, 1958, for exploratory laparotomy. On the next day, 815 c.c. of thin, hemorrhagic fluid was removed from the right pleural space. Uterine curettage and biopsy of the posterior vaginal wall revealed late secretory endometrium without tubercles and chronic inflammation of the vaginal wall. Pleural fluid reaccumulated rapidly, and 8 days after the previous thoracentesis 900 c.c. of thin bloody fluid was removed. On the following day, exploratory laparotomy revealed fallopian tubes that were patent but adherent to the posterior aspect of the ovaries. The ovaries were adherent to the region of the cul-de-sac, which was obliterated by marked inflammatory reaction. There were 100 to 150 c.c. of brownish fluid within the pelvic cavity. A 3 by 3 mm. bluish nodule, suggesting endometriosis, was adherent to the appendix. Biopsies were taken of scattered plaques of hemorrhagic tissue on the surface of the tubes and ovaries. A 2 by 2 cm. bluish cystic structure was removed from the omentum. Histologic examination of these biopsies demonstrated endometriosis (Fig. 6). Surgical sterilization was not performed.

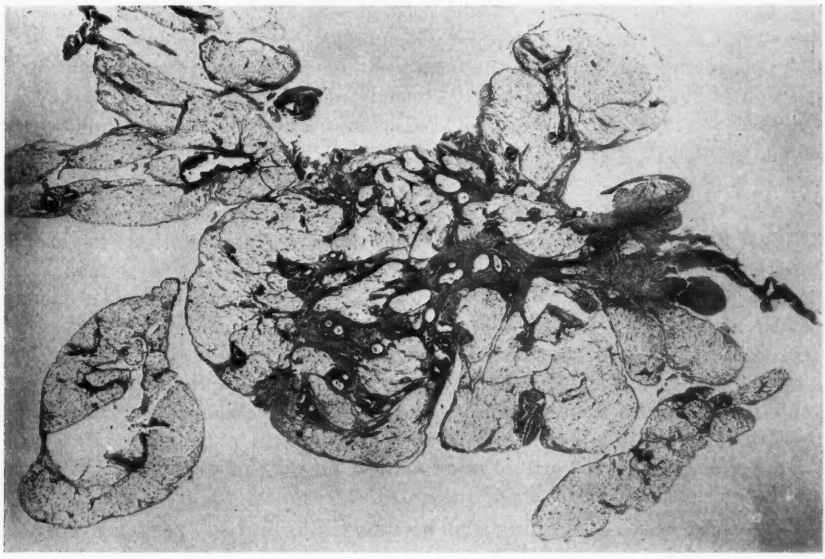
A trial of Enovid therapy (17 alpha-ethynyl-17-hydroxy-5 [10]-estren-3-one with ethynyl estradiol 3-methyl ether), 10 mg. per day, was instituted in an effort to obtain suppression of ovarian function and to prevent the reaccumulation of pleural fluid. Since discharge from the hospital on June 21, 1958, the pleural effusion has not reappeared and the patient is being followed in the outpatient department.

DISCUSSION

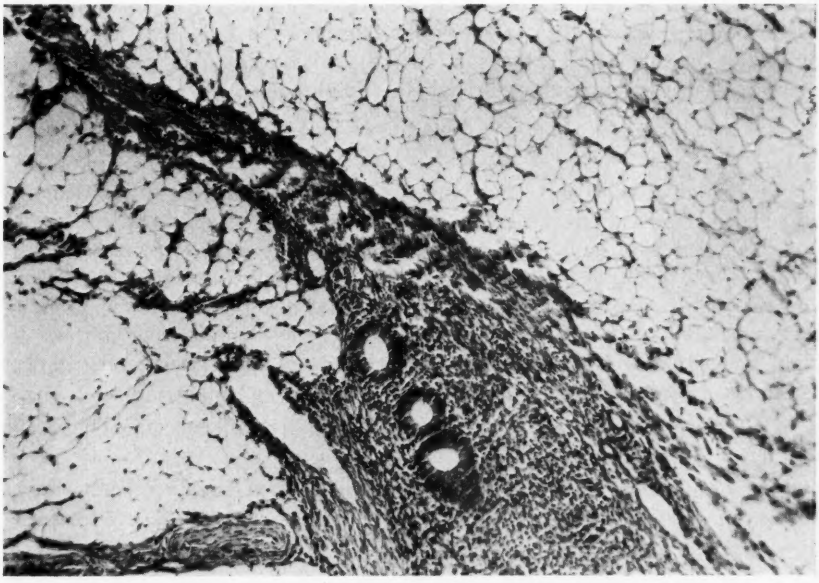
Two histologically proved cases of endometriosis involving the pleura have been reported previously. Brews[1] mentioned a 39-year-old woman, with ascites and right pleural effusion, who had diffuse abdominal endometriosis, involvement of the right diaphragm, and a small communication between the peritoneal and right pleural cavities. The patient was well for 3½ years following irradiation of the ovaries. Pleural involvement by endometriosis is not documented.

Barnes[2] and Nicholson[3] separately presented the same case of a 25-year-old married nulliparous woman who had recurrent hemorrhagic pleural effusion. At thoracotomy, a yellow "pellicle" was stripped from the right lung and microscopic sections showed typical endometrial tissue. A 200 mg. pellet of testosterone was implanted subcutaneously and she was advised to become pregnant. She apparently was unable to conceive and subsequently had recurrent pleural effusion. Oophorectomy was ultimately performed and endometriosis of the pelvic peritoneum was found.

Lattes and associates,[4] while presenting a case of endometriosis of the lung, referred to a report by Büngeler and Silveira[5] of a 42-year-old woman who died of "chronic pneumonia." Both pleural cavities were obliterated and there was histologic evidence of endometriosis in three small nodular masses on the right upper pleural surface. Büngeler and Silveira[5] attributed the pleural endometriosis to metaplasia or heteroplasia of the pleural mesothelium. According to this theory, peritoneal endometriosis is derived from metaplasia of the peritoneum. Since both mesothelial spaces arise from a common anlage, the embryonic coelomic cavity, it seemed reasonable that pleural endometriosis might similarly be the result of metaplasia.



A.



B.

Fig. 6.—*A*, Section of omentum containing endometrium. (Hematoxylin and eosin; ×7; reduced 1/10.) *B*, Higher magnification of omentum showing well-developed endometrial glands and stroma in fat tissue. (Hematoxylin and eosin; ×115; reduced 1/6.)

Lattes[4] described a 34-year-old woman with hemoptysis associated with menstruation of 3 years' duration. Roentgenograms of the lungs showed a coin lesion and the resected specimen contained endometrium with decidual reaction of the stroma; pleural involvement was not mentioned. The patient apparently was cured by pulmonary resection. The authors believed that the lesion resulted from hematogenous spread and implantation of endometrium during a previous cesarean section and uterine curettage.

Charles[6] described a case of ascites and hemorrhagic pleural effusion in a 33-year-old nulliparous female with diffuse abdominal endometriosis established by exploratory laparotomy; a right salpingo-oophorectomy was performed. One year later, ascitic fluid reaccumulated and there was such diffuse peritoneal disease at the second laparotomy that removal of the remaining ovary was impossible. Pleural effusion had not recurred since the first hospitalization. The author postulated that fibrosis of the pleuroperitoneal sinuses had now prevented transdiaphragmatic transfer of ascitic fluid. Postoperative irradiation was administered to the remaining ovary. The patient remained asymptomatic during a one-year follow-up. Unfortunately, no histologic evidence of pleural involvement by endometriosis is presented.

The presence of a communication between the pleural and peritoneal cavities, demonstrated by the prompt development of a right pneumothorax following diagnostic pneumoperitoneum in this case, is of considerable interest. Sampson's theory that pelvic and abdominal endometriosis results from the retrograde expulsion of endometrium into these areas through the fallopian tubes may be applicable in this case. Extension into the thorax is made possible by the presence of a communication through the diaphragm.

SUMMARY

A case of endometriosis involving the pleura is reported. The patient had recurrent hemorrhagic pleural effusion, increased menses associated with moderate abdominal pain, and inability to conceive. The diagnosis was considered clinically and confirmed by histologic examination of tissue from the pleural and peritoneal cavities. Diagnostic pneumoperitoneum was followed promptly by pneumothorax, indicating the presence of a communication between the right pleural and peritoneal space, and permits the application of the implantation theory in explanation of this unusual site of endometriosis.

Two documented cases of pleural endometriosis and one of endometriosis of the lung are cited.

This pathologic process should be considered in a young woman with recurrent hemorrhagic pleural effusion of obscure etiology. Early treatment, directed at suppression of ovarian function, will provide relief of the debilitating symptoms secondary to the continuing accumulation of the irritating bloody fluid in the pleural space.

We are indebted to Mr. Milton Kurtz who is responsible for the illustrations used in this paper.

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A DISPOSABLE FILMING PUMP-OXYGENATOR

Experimental and Clinical Use in 70 Patients

John J. Osborn, M.D., Frank Gerbode, M.D., Herbert Perkins, M.D., Mark Braimbridge, F.R.C.S., Denis Melrose, M.B., and Paul Kahn, A.B., B.S., San Francisco and Berkeley, Calif.

ARTIFICIAL lungs or oxygenators usually form their blood-gas exchange surface in one of three ways: (1) by bubbling gas through blood,[1-3] (2) by filming blood over a large surface area,[4-7] or (3) by spreading blood between two thin diffusion membranes.[9] Of these methods, the bubbling method is by far the simplest but many workers have found filming methods (usually using stationary screens or rotating disks) more satisfactory. The membrane oxygenators in turn may well be superior to filming systems but they have particular problems of their own in manufacture. Design of an oxygenator, like the design of an airplane, requires that the designer list his desires in some order of priority and then reach a difficult compromise between extremes.

We have previously described a filming oxygenator which handled blood with very low measurable damage.[10, 11] For this reason and because experimental results were excellent, we have felt that it has been worth while to sacrifice some of the fine simplicity of the bubble-oxygenator for the apparently better results of a filming system.

In the requirements for a practical blood oxygenator, cleanliness and disposability rank very high. It is essential to a successful perfusion that all surfaces which the blood touches be pyrogen-free and scrupulously clean. We have, therefore, evolved a filming oxygenator in which the filming surface is of vinyl plastic film, so that the "artificial lungs" can be supplied sterile and ready to use and then be thrown away after use.

It has been shown that in stationary filming systems, a smooth filming surface is less efficient than a "rough" surface in allowing oxygen uptake. Gibbon[12] and, also, Gaertner and Kay[13] demonstrated the increased efficiency of screen surfaces over simple flat ones. The best explanation for this is that when a film

From the Departments of Pediatrics, Surgery, and Medicine, Stanford University School of Medicine, San Francisco, Calif., and Cutter Laboratories, Fourth and Parker Streets, Berkeley, Calif.

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falls vertically in an oxygen atmosphere, the surface tension on the falling surface at the gas-blood interface holds the surface red cells rather rigidly in position, so that there is little, if any, mixing of the surface with cells deeper in the falling film. So, no matter how long the vertical fall of the film, the surface cells become saturated quite early in the fall while the deep cells receive essentially no contact with oxygen. Of course, if the falling film can be made turbulent, with complete mixing into the surface film during its fall, the oxygen uptake should be enormously increased. There is some evidence that a screen surface produces enough turbulence to produce some mixing, but the data of Gaertner and Kay[13] seem to show that mixing on a screen is not complete, because oxygen uptake over the first part of a fall greatly exceeded the uptake over the last part at all given flow rates.

However, turbulence from a rough surface is not the only way to mix surface and deep blood in a filming system. There are probably many ways, but one which we have found rather satisfactory in practice is to produce rapid changes in the thickness of the film and let the blood run down in rather thick waves, one wave following the other. A smooth plastic surface on which a blood film is produced by a slowly moving oscillating jet allows blood oxygenation with approximately the same efficiency as a screen surface. We have, therefore, been able to produce a filming system in which blood is laid down on a disposable vinyl surface by a moving low-pressure jet. This basic system appears to us to retain the desirable features of other filming systems, and to have the great advantage that it can be essentially prefabricated and then disposed of after use.

DESCRIPTION OF APPARATUS

The Oxygenating Unit.—Oxygenation is accomplished by a blood film spread on the inside of a series of partly inflated polyvinyl bags, each 76 cm. long and 40 cm. wide. The bags are constructed of a specially prepared polyvinyl sheeting which is extremely hydrophobic and is essentially free of soluble plasticizer.* The bags are inserted into a Lucite-retaining frame and then inflated against the frame with oxygen containing 6 per cent carbon dioxide.

Blood is introduced into the top of each bag through a silicone-treated glass manifold ending in a Y-shaped distributing tube for each bag. The distributing Y-tubes oscillate or rock back and forth inside the bags and spread the blood into an even film on the inside of the bag at the top. The apparatus is shown diagrammatically in Figs. 1 and 2.

The bottom of each bag acts as a blood reservoir and drains into a common collecting manifold. Blood is continuously withdrawn from the collecting manifold and pumped back to the distributing tubes at the top of each bag, to maintain the film. There is no bubbling or foaming and so no antifoam is used.

The Pumps and Catheters.—The pumps are the Gibbon type consisting of several parallel tubes pressed by a revolving pair of rollers. It is, therefore, several parallel pumps, depending on the number of tubes pressed by the same

*Manufactured by Cutter Laboratories, Fourth and Parker Streets, Berkeley, Calif.

rollers. We use one tube or pump for each set of two or three lung-bags; all these pump-tubes being driven by the same roller, as shown in the diagram. A separate Gibbon roller-pump drives the arterialized blood back to the patient. The original Gibbon pumps were designed to press on rubber tubing, but we have modified ours to use disposable plastic tubing. Our basic flow pattern is essentially the Gibbon system. In use, the recirculating or oxygenating pump is set to run at a constant speed, while the arterial pump is either directly controlled by the operator or linked to the venous return by the automatic control system to be described below.

Collection of blood from venae cavae has been through soft plastic catheters of appropriate size, introduced through purse-string sutures in the right atrium. These catheters come together to a Y-connector and drain by gravity to one end of the collecting manifold of the pump-oxygenator as shown in Fig. 2. A study of the flow diagram (Fig. 2) will show that venous blood cannot pass in any quantity from the venous end of the collecting manifold to the arterialized end without passing over the oxygenating film in the bags. Arterialized blood is collected from the other end of the manifold and passed through a combined filter and bubble trap. The return to the patient is through a stainless steel catheter in the femoral artery. All metal parts are treated with Monocote[E]* prior to each use.

The Electronic Control System.—The lung-bags and their input and output tubes are held as described before in a Lucite-retaining frame. This frame is suspended from a pair of spring-steel arms with strain gauges placed at their bend-points. Essentially, these spring-steel arms form the bending beams of a delicate scale whose sensing element consists of the strain gauges. Weight of the entire system is indicated on a Brown indicator-controller which is electrically linked to a motorized variable transformer in such a way that if the weight on the entire lung unit with its blood reservoir drops below a preset value, the output rate of the arterial pump is proportionally reduced, until it is finally stopped. Therefore, the weight (hence the volume) of the blood in the lung and reservoir system controls the output of the arterial pump. If the amount of blood in the system decreases below the chosen setting, the output will be reduced and the level of blood in the lung will be maintained constant. This means that the arterial pump will not suck air if the input to the lung decreases so that the blood reservoir level falls, and it also allows the operator to maintain a very accurate balance between blood in the machine and blood in the patient.

Each pump is operated at a speed which can be manually varied by the operator. They are driven by direct current motors drawing power through appropriate rectifiers from an alternating current 110 volt source. Speed is controlled by variable transformers altering the voltage of the motor armatures. An alternate control-box, drawing from the hospital emergency direct current supply, has been provided in case of power failure.

*Manufactured by Armour & Company, Division of Armour & Company, Kankakee, Ill.

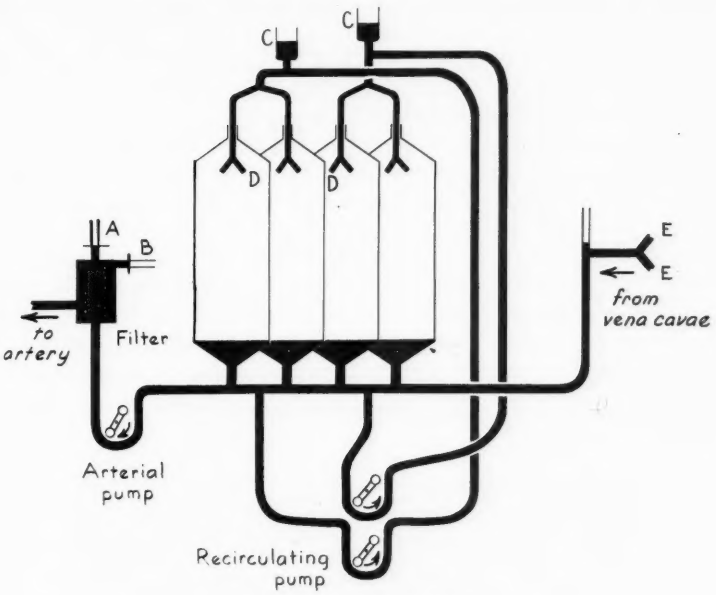

Fig. 1.—Diagram of flow.

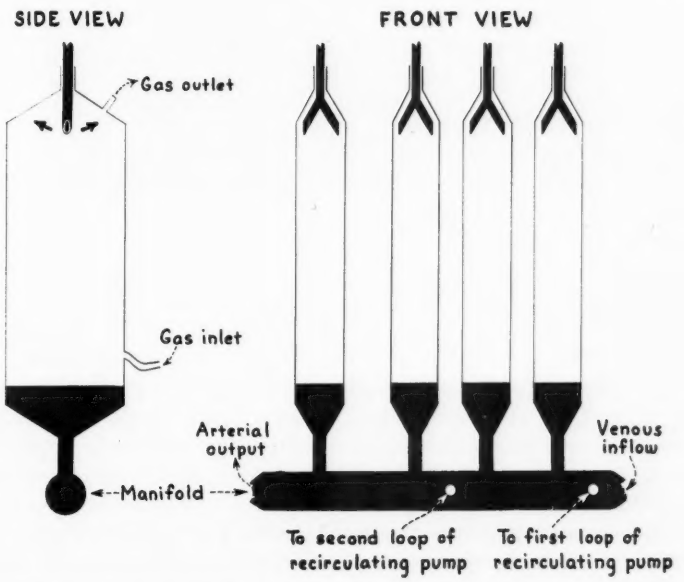

Fig. 2.—A single bag shown in detail and 4 bags shown in place, seen from the narrow edge.

TECHNICAL DETAILS OF APPARATUS AND PROCEDURE

The arterial pressure is monitored by polyethylene tubing inserted into the internal mammary artery. This avoids extra skin incisions and, once inserted, causes no further difficulties.

The venous pressure is monitored by a polyvinyl catheter inserted through the long saphenous vein in the groin. This vein is used for two reasons: because it is immediately adjacent to the femoral artery which is exposed for the arterial return from the pump and because it has been particularly valuable to leave this catheter in position for the first 24 hours. Concentrated solutions, such as 10 per cent calcium chloride, can then be given with no fear of thrombosis, as the tip of the catheter rests in the inferior vena cava. The conceivable hazard of emboli has not so far occurred in our experience. Removal of the catheter is performed with the patient in a slight Trendelenberg position, which is maintained for 10 minutes. Surprisingly, no troublesome hemorrhage has resulted from this maneuver.

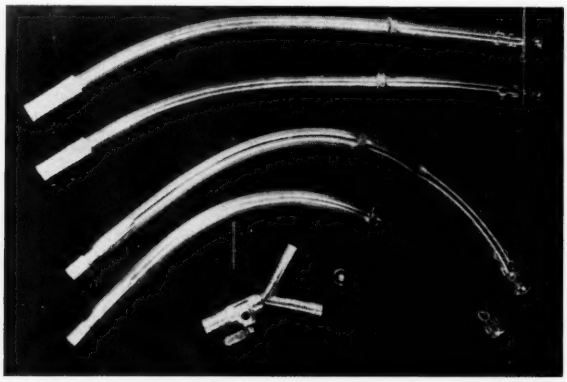

Fig. 3.—Two sizes of venous catheters with the Y-connectors. These have been autoclaved with small rubber band near tip. The fourth has been cut where the band was to form a whistle-tip ready for use.

For the withdrawal of blood from the venous side of the patient, polyvinyl catheters are chosen of a size as large as can be inserted into the vena cava via the right atrium. This is of considerable importance. Some difficulty was encountered in the earlier cases in this series, before the importance of a large venous return was realized. Any size tubing can be made to have a whistle-tip end if a constricting rubber band is placed around it before autoclaving. The end beyond the constriction is cut off right at the narrow point just before the catheter is used. Four large side holes are made near the tip of each tube. The catheters are joined to a length of 7/16 inch polyvinyl tubing by means of steel Y-tips with an air vent on the top. All air can be aspirated through this vent with a syringe. The air vent is equipped with a small occluding plug to prevent aspiration of air, if a tap is inadvertently opened (Fig. 3). The arterial side of the pump-oxygenator is connected to the patient by 5/16 inch polyvinyl

tubing. A steel catheter approximately 1½ inches long is inserted into the common femoral artery. A set of various sizes of these catheters allows a suitable one to be chosen so that it is as large as can be easily inserted into the artery. If too large a catheter is forced into the artery, it has been found that the stretching results in spasm proximal to the catheter and a lower flow is allowed than with a smaller catheter which slips in easily. The insertion of a reasonably large catheter is assisted by careful dissection of the femoral artery and the use of papaverine, both of which prevent spasm of the vessel. The catheter is tied in with heavy braided silk over a short piece of latex tubing to prevent damage to the vessel and it has been felt important that the similar tie which occludes the distal end of the artery should, also, be carried around the cannula to keep it aligned correctly in the wound. We have not found it necessary to insert a long catheter into the femoral artery with its tip lying in the aorta, as a perfectly adequate flow can be maintained through a short catheter and this very shortness keeps the resistance as small as possible. Steel catheters are connected by means of a short length of 5/16 inch polyvinyl tubing to a steel connector with an air vent on the top and then to the tubing from the machine. Air is easily removed by means of a syringe from this point, small bubbles which adhere to the side of the tubing being dislodged by tapping the tubing with a clamp.

Many of our fittings are adapted from those used at the Mayo Clinic. All are the result of extensive trial and error. Hard experience has taught us to give careful attention to small details of design and technique.

CORONARY BLOOD RETURN

Most cardiotomies in this series were performed with induced cardiac arrest, using potassium citrate, so that the coronary venous return was reduced. Yet, sometimes, even when the heart was stopped, there was a large intracardiac return from an aberrant vessel and, of course, when the heart was not stopped, coronary venous return was normal. Rarely an intracardiac blood flow of up to 1.5 L. per minute has to be sucked out of the open heart.

When large flows have to be aspirated from the open heart, it is obviously necessary to return this blood to the general circuit. In earlier work, we had difficulties following such large "coronary returns" which we felt might be attributed to air embolism from bubbles trapped in the sucked blood.[15] We now believe that the return of aspirated blood must be treated as a major problem and must be carefully engineered.

Two coronary suckers are available; one high pressure and one low pressure, either of which may be used depending upon the amount of coronary return. One tip is specially adapted so that it can be left inside the heart near the largest source of blood, such as inside the right atrium; the other is a slightly modified surgical suction tip for clearing the actual point on which the surgeon is working. These two separate suction lines lead to separate pieces of tubing on a third Gibbon-type pump, which discharge into a silicone-coated glass reservoir. Blood is allowed to stand in this reservoir as long as possible before being discharged back into the general circuit, to allow small bubbles to rise. We always maintain several inches of blood in this reservoir, so as to be particularly sure

that "light blood" (presumably containing trapped air) will not be returned to the patient. No silicone antifoam is used in the circuit, except at the very top edge of the coronary reservoir which is lightly coated, for the rare emergency, when foaming is excessive.

ELECTIVE CARDIAC ARREST

Elective cardiac arrest is used according to the Melrose technique[14] in almost every case. It is performed with a solution of 1 c.c. of 25 per cent potassium citrate for every 10 c.c. of fully oxygenated heparinized blood. The amount prepared varies with the size of the heart and expected difficulties. A short bevelled No. 16 curved needle is connected by means of extension tubing to a 3-way tap in which two 30 c.c. syringes containing the potassium blood mixture

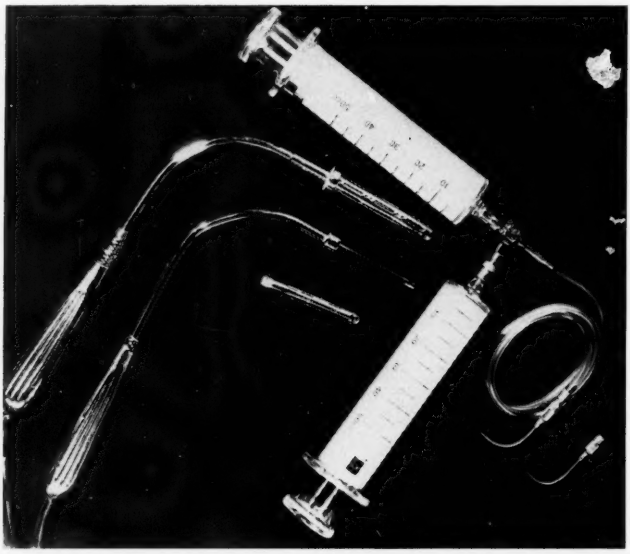

Fig. 4.—Syringes for injection of blood and potassium and intracardiac suction tips.

are inserted. A third 30 c.c. syringe is kept in reserve. The advantages of this method of stopping the heart are that the needle can be inserted by the surgeon and held carefully in the center of the aorta lumen, without interference from the syringes, thus, preventing untoward perforations. Injection of the solution is performed by the assistants. Having more than one syringe available obviates difficulty in the case of one sticking.

RESULTS

Results in Animals.—This apparatus was used in 29 consecutive dogs for total bypass of the heart and lungs. During all the earlier runs, a commercially available plastic material was used as a film surface. This material contained a toxic, semisoluble "non-stick" compound. Ten out of the 16 animals died.

For subsequent animals, we used first carefully washed and treated commercial polyethylene film and then a plastic film specially formulated for use

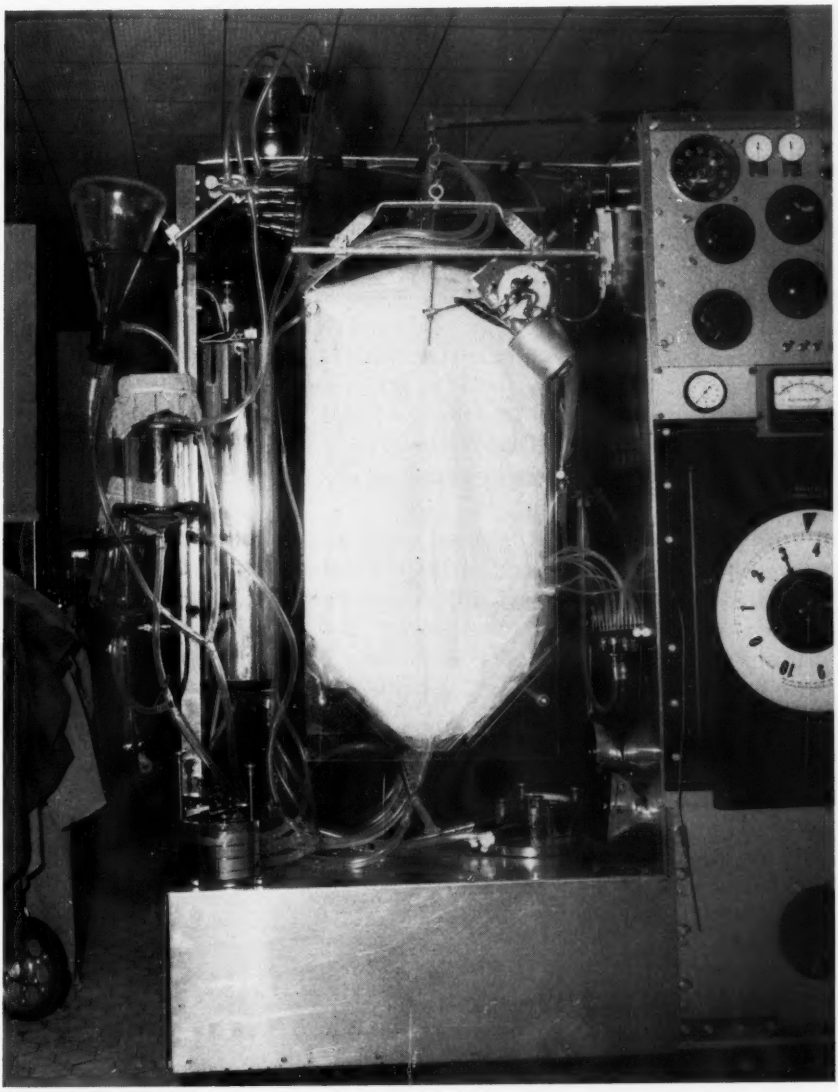

Fig. 5.—Photograph of assembled apparatus showing inflated bags in their frames and control panel.

with blood.* This is a vinyl plastic which is remarkably hydrophobic and contains no toxic plasticizer. In these animals, there were no deaths which could

*From Cutter Laboratories, Fourth and Parker Streets, Berkeley, Calif.

be attributed to the method of bypass. In most experiments, there was no attempt to maintain sterility (because of personnel shortage). Several dogs died of infection several days after the operation. Using then the 2-day survival as the end-point, only one of the 13 animals died and this was an animal in which the tricuspid valve was removed surgically. He died rather rapidly in acute right ventricular failure. Each animal was subjected to ventriculotomy. The average duration of the ventriculotomy was 14 minutes. Seven out of the 13 animals went into ventricular fibrillation briefly when the blood was readmitted into the coronary arteries. This fibrillation either reverted spontaneously or was easily reverted to normal rhythm by electric shock. It was never a serious problem.

Results in Patients.—The apparatus has been used during intracardiac surgery on 70 patients. Details of these operations will be the basis of another communication. It is appropriate to say that this series of patients included both children and adults with diagnoses ranging from congenital heart disease to tumor of the heart. Some were in extremely poor condition when surgery was undertaken. Of these 70 patients, 18 died. The other 52 are living and improved or essentially cured. The great majority of deaths have been in patients with severe pulmonary hypertension, or in severe failure at the time of operation.

Severe bleeding has not occurred except in one case in which, on a second thoracotomy, a leak was found in the ventricular incision. The leak was repaired and the patient did well. Postoperative fever has rarely been a serious problem, although a temperature rise of 1° to 1.5° C. is rather common. The patients have usually been eating on the second or third postoperative day and have been ambulatory on the eighth or ninth day.

SUMMARY

A filming oxygenator which is almost totally disposable is described.

In basic plan, it resembles a Gibbon oxygenator, but the screen filming surfaces of the Gibbon lung have been replaced by disposable vinyl plastic bags.

In use in 70 patients, severe postoperative reaction or bleeding, traceable to the oxygenator, has not occurred.

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TECHNIQUE FOR TRANSSEPTAL CATHETERIZATION OF THE LEFT ATRIUM: PRELIMINARY REPORT

Constantin Cope, M.D., East Orange, N. J.*

CATHETERIZATION of the left heart has been approached in many ways. Björk[1] developed the right paravertebral technique; Radner[2] tried the suprasternal route; Allison[3] and Facquet[4] punctured the left atrium through the left bronchus; Ponsdomenech[5] and Brock[6] pierced the left ventricle. These techniques are unfortunately associated with some morbidity, the most serious of which is pericardial tamponade.

A method for catheterizing the left atrium through the interatrial septum will now be described. The principles which make this technique feasible are: (1) The septum of a human heart may be described as facing downward, anteriorly and to the right; in other words, if a needle with a slight terminal curve turned posteriorly and to the left were to come up the inferior vena cava, it would make contact with the septum at approximately a 45 degree angle and would perforate it in the region of the fossa ovalis.† (2) A large-sized polyethylene catheter can be introduced percutaneously very easily into the femoral vein by means of the catheter replacement technique of Seldinger.[7] (3) A long, stainless steel, thin-walled needle, long enough to reach the left atrium from the thigh, is surprisingly flexible and is, moreover, malleable enough to be shaped manually into any required curves.

INSTRUMENTATION AND TECHNIQUE

The instrument is essentially a compound needle about 70 cm. long.‡ The outer cannula is made of flexible thin-walled 17-gauge needle tubing. The inner needle is a solid, much stiffer, closely fitting stylet whose sharpened end protrudes 2 to 3 mm. beyond the tip of the cannula.

The compound needle fits within a sheath of polyethylene tubing, PE 240§ (internal diameter 1.67 mm.; outer diameter 2.42 mm.), the end of which is

The animal work and first clinical trial of this technique were all performed in the departments of Dr. Charles P. Bailey and Dr. Harry Goldberg, Hahnemann Hospital, Philadelphia, Pa.

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*Resident in Chest Diseases, Veterans Administration Hospital, East Orange, N. J. Requests for reprints should be addressed to Dr. Cope, Kennedy VA Hospital, Memphis, Tenn.

†This interesting relationship was first suggested to the author by Dr. M. Calabresi, Chief of Cardiology, Veterans Administration Hospital, West Haven, Conn.

‡Available from Becton-Dickinson Company, Rutherford, N. J.

§Available from Clay-Adams Company, New York City.

tapered down to the external diameter of the cannula by stretching[8] and is pierced by several lateral openings (Fig. 1). The proximal part of the tubing is attached to a system of connectors in series, comprising a plastic tubing adapter,* a 3-way adapter† the side arm of which is connected to a perfusing bottle of saline or a pressure manometer and a Tuohy-Borst adapter† through which the long needle can be introduced.

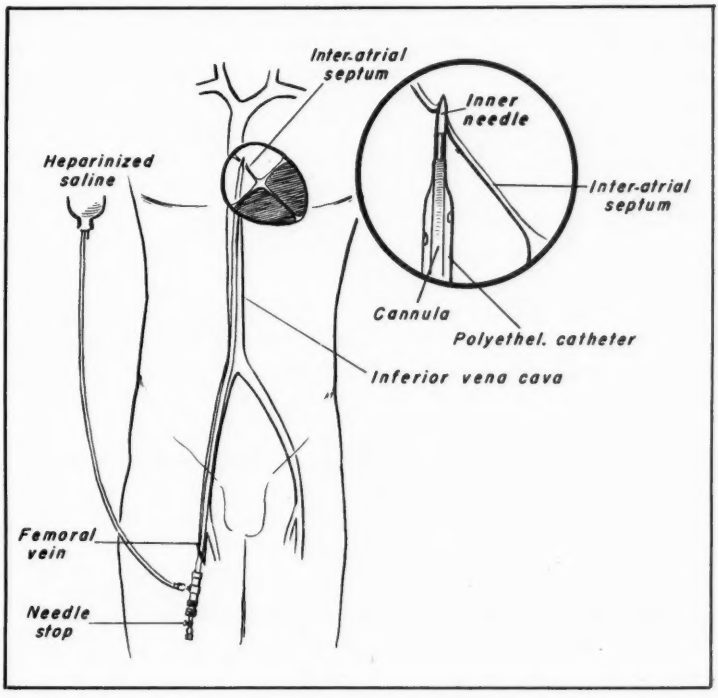

Fig. 1.—Plastic catheter passed up the right femoral vein to the right atrium. It contains a long needle which is perforating the interatrial septum. Inset demonstrates the attenuated tip of the catheter with side holes with protruding cannula and stylet point.

The polyethylene catheter is inserted percutaneously into the right femoral vein by means of the Seldinger method and is pushed up the inferior vena cava to the level of the right atrium.

To be certain that the cannula on its way up the inferior vena cava does not perforate its polyethylene sheath, a flexible Seldinger guide (size PE 160)‡ is first introduced into the cannula and made to protrude about 8 cm. distally so as to form a soft guiding tip. The cannula with its wire is now inserted through the polyethylene catheter and, under fluoroscopic guidance, is pushed

*Available from Clay-Adams Company, New York City.
†Available from Becton-Dickinson Company, Rutherford, N. J.
‡Available from Ohio Chemical and Surgical Equipment Company, Madison, Wis.

up the interior vena cava to its entrance into the right atrium. The Seldinger wire is now withdrawn and is replaced by the stylet which is inserted up the lumen of the cannula to within 1 to 2 cm. of its tip.

The cannula is pushed up to the needle stop which has been previously set to indicate that the end of the cannula is protruding about 3 to 4 mm. beyond the catheter tip. Now, under continuous fluoroscopic guidance, the needle catheter complex is gently pushed up and manipulated until it is seen and felt to impinge against the atrial septum in the region of the fossa ovalis.

The pointed stylet is now pushed up and allowed to protrude and, with gentle pressure, is advanced about 1 cm. so as to perforate the septum. The stylet point is now withdrawn within the cannula. At this juncture, while the needle is held firmly, the attenuated tip of the polyethylene catheter is further advanced[8] through the septum into the left atrium by pushing the proximal end of the catheter. The compound needle is now withdrawn all the way leaving only the polyethylene catheter within the patient.

The catheter can now be used for sampling pressures within the left atrium and possibly within the left ventricle if a smaller polyethylene tube is passed through the catheter and allowed to float down past the mitral valve. Other uses include injection of indicator dyes for dye dilution studies and radiopaque media for ventriculography and aortography.

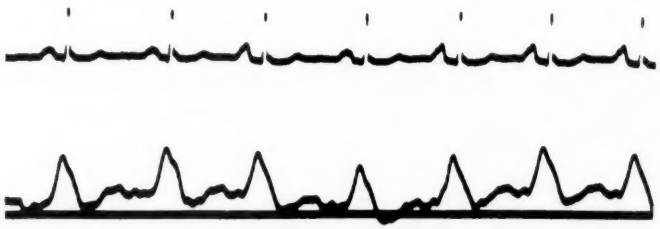

Fig. 2.—This pressure tracing was taken with the catheter tip resting in the left atrium. The patient has early mitral stenosis.

RESULTS

This method was first tried out on dogs unsuccessfully. Careful study of the dog atrial septum revealed that it is extremely small and is placed in a sagittal plane in such a way that it cannot be reached by a needle introduced via the inferior vena cava or the superior vena cava.

The human heart septum was thought to have a more accessible plane. After reviewing many angiocardiographic studies of the human heart, it was decidedly felt that the septum did face down, forward, and to the right. This was confirmed during the course of several catheterizations of the inferior vena cava under fluoroscopy, when a soft tip needle probe was seen to impinge against the atrial septum. Final confirmation of the feasibility of puncturing the human septum came when, during a mitral commissurotomy, the needle was passed up the inferior vena cava by the technique described above, and,

with a monitoring finger in the right and then the left atrium, the needle, without any guidance, was pushed very easily through the septum just above and to the left of the fossa ovalis.

Since that time the left atrium of 2 patients has been successfully catheterized under fluoroscopy by the method described above. During perforation of the septum, the patients experienced a "funny feeling" in the throat which was associated with a few fleeting runs of auricular premature contractions. This sensation subsided as soon as the catheter tip had entered the left atrium (Fig. 2). In the second patient, the polyethylene catheter would not follow the needle through the septum because the catheter tip had become frayed, probably during its passage into the femoral vein. However, excellent left atrial pressure tracings were obtained through the metal cannula.

DISCUSSION

Dangers.—This technique brings to mind immediately several inherent dangers.

1. *Perforation of the inferior vena cava:* The polyethylene sheath, the flexibility of the cannula, the protruding flexible guide wire are all features calculated to prevent such an occurrence. Moreover, since this procedure is done under fluoroscopic guidance, obstruction or unnegotiable curves can be noted immediately and the procedure discontinued.

2. *Thrombosis, embolization, enlargement of the puncture hole into a septal defect:* Animal work has shown that it is very difficult to create an artificial interatrial defect, because it closes over within a few days. Repair of interatrial septal defects in human beings with the necessary needle perforations and use of suture material do not seem to be associated with any greater incidence of embolization. Finally, perforation of the atrial septum is probably a fairly common accidental occurrence in locating the left atrium by the paravertebral approach, and this again does not seem to be associated with increased morbidity.

3. *Distortion of septal plane with accidental perforation of structures other than the septum:* Punctures of the base of the aorta, pulmonary conus, and posterior wall of the atrium into the mediastinum are probably possible; however, all these sites have been punctured accidentally by other standard approaches for left heart catheterization with apparently few serious consequences.[9, 10] Indeed, it is doubtful whether there can be any greater danger in needle perforation of an organ from its lumen outward than from without.

Advantages.—

1. Any blood leak is intracardiac and of low pressure. If done properly, this procedure should not be associated with any pericardial or extracardiac hemorrhage.

2. The procedure is performed under basal conditions with the patient lying comfortably on his back. Right heart catheterization can be performed simultaneously.

3. A large-gauge catheter can be easily introduced which allows accurate pressure tracings and radiopaque dye injections.

4. This technique will probably be of greatest use in patients with valvular heart disease. However, some congenital anomalies, not affecting the interatrial septum, might also be suitable for study by this method.

The purpose of this paper is to describe a new approach to the catheterization of the left atrium which seems to have definite advantages. It has been done successfully in 2 patients. It is hoped that the early publication of this paper will stimulate more extensive trial of this technique for a better and more comprehensive evaluation of its possibilities.

SUMMARY

A technique is presented which allows the catheterization of the left atrium in man through the interatrial septum by means of a long needle introduced percutaneously in the femoral vein.

The author is very much indebted to Dr. Charles P. Bailey and Dr. Harry Goldberg for permission to use the facilities of their departments at Hahnemann Hospital and for their help in making this technique a practical reality.

Illustrations were prepared by the Illustration Department, Veterans Administration Hospital, East Orange, N. J.

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THE TRANSPLANTATION OF URINARY BLADDER MUSCLE INTO THE MYOCARDIUM

Rollin A. Daniel, Jr., M.D., Sam L. Clark, M.D., and John L. Sawyers, M.D., Nashville, Tenn.

In 1921, Carey reported a change in the appearance of the muscle of the urinary bladder of a dog when the animal's bladder was subjected to intermittent distention and relaxation in a range approximating the intracardiac pressures. According to the author, the muscle fibers developed striations and assumed the appearance of cardiac muscle. The experiments reported here were undertaken in an effort to (1) test the validity of Carey's observations, and (2) test the feasibility of the use of free grafts of smooth muscle to replace defects in the wall of the ventricle of the dog's heart.

METHODS

Six mongrel dogs were used. Each animal was anesthetized with intravenous Nembutal and the trachea intubated. The heart was exposed through an intercostal incision in the right fourth interspace and a long pericardial incision placed anterior to the phrenic nerve. The urinary bladder was exposed through a short, lower abdominal midline incision.

A curved intestinal clamp was placed across the fundus of the urinary bladder and a section or block of bladder wall was excised which included the peritoneum and bladder muscle and, in four of the experiments, the mucosa. The defect was closed with two rows of interrupted silk sutures. The block of bladder wall, approximately 1.5 cm. square, was immediately placed in normal saline solution.

Following atrial-caval infiltration of 1 per cent procaine solution, a curved, toothed, ductus clamp was applied to the wall of the right ventricle of the animal's heart. A block of the wall of the ventricle near the apex and at a relatively avascular site was excised. This tissue measured roughly 1.5 cm. in diameter. The section of bladder wall was put into the cardiac defect and sutured in place with interrupted sutures of fine silk which were inserted deeply and close together.

Following removal of the clamp from the ventricle, the transplanted tissue did not change in appearance. No bleeding occurred through the suture lines.

From the Departments of Surgery and Anatomy, Vanderbilt University School of Medicine, Nashville, Tenn.
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Irregularities of the heart rate, which occurred while the clamp was in place, were succeeded promptly by a normal rhythm. The animals were given Chloromycetin postoperatively to control infection, but no anticoagulants were used.

In the first two experiments, the transplants were of thick blocks of bladder wall which were implanted into ventricular defects, that extended down near, but did not include the endocardium. In the remaining four experiments, full-thickness grafts of bladder wall, including peritoneum and mucosa, were implanted into full thickness defects of the ventricle wall including the endocardium. In three of these experiments, the bladder mucosa was placed inside facing the ventricular cavity and, in the fourth, the mucosa was placed outside, or contiguous to the epicardium, with the peritoneum covering the bladder muscle presenting inside the ventricle.

RESULTS

All 6 dogs recovered from the operative procedure without complications. The hearts of all were examined at autopsy after various periods of time and in each the parietal pericardium was adherent to the transplant and to the epicardium immediately surrounding the graft. There was no evidence of leakage of blood in any experiment.

The 2 animals in which patches of bladder muscle were transplanted into craters of the myocardium were sacrificed 14 days after operation. Microscopic study of the specimens revealed areas of degeneration of bladder muscle fibers and invasion of the transplanted tissue by leukocytes and fibroblasts, with inflammatory changes in the myocardium immediately adjacent to the graft, but the major portion of the graft was intact and normal in appearance.

Of the 4 animals in which full-thickness grafts were used, one died 12 days after operation and a second on the twenty-third postoperative day. The cause of death was not determined at autopsy. There was no evidence of infection or of hemorrhage. However, examination of the hearts revealed small thrombi within the right ventricle and adherent to the transplant in each instance. There was no evidence of embolization in the thoracic or abdominal viscera but the brain was not examined in either experiment. In each of these, the bladder mucosa had been placed toward the ventricular cavity.

The 2 remaining dogs were sacrificed 12 and 51 days after operation. In the experiment ending on the twelfth postoperative day, the graft had been applied with the bladder mucosa within the ventricle. In the experiment ending 51 days after operation, the graft was placed with the mucosa toward the outside of the heart and the peritoneal surface of the bladder muscle within the ventricle.

The incisions in all experiments appeared to be well healed. There appeared to be some contraction in the size of the grafts which grossly were pale and gray in color as compared to the surrounding cardiac muscle. Except for the small mural thrombi in 2 animals mentioned above, the inner surfaces of the ventricles were smooth. The size of the heart chambers appeared to be normal.

Microscopic studies of sections through the grafts stained with hematoxylin and eosin revealed that, although some of the smooth muscle of the transplanted bladder wall degenerated, much of it survived and retained a normal appearance in each animal. Connective tissue newly formed at the margin of the graft was well developed and, in the 51-day experiment, this had invaded and freely mingled with the surviving smooth muscle.

The transitional epithelium of the bladder transplant survived well whether it was facing into the ventricular or the pericardial cavity. Proliferation of it was more evident in the specimens in which it faced the ventricular cavity.

In addition to the preservation of mucosa and muscle described, there was the expected reaction at the margin of the graft. Portions of silk suture were surrounded by minimal inflammatory change, and some large areas of infiltration by leukocytes were encountered. There were also scattered, near the graft margins, stained granules of what appeared to be small calcareous deposits, but no true bone formation was found.

The experiments fail to confirm Carey's report of the conversion of smooth muscle to a striated form resembling cardiac, even though the intermittent pressures applied to the graft would seem in this instance to be ideal.

These experiments demonstrate that portions of bladder used as patches for defects in the heart wall, even of full thickness, survived without sloughing and that the elements of the grafts, connective tissue, muscle and epithelium, persisted as obviously viable tissues for long periods.

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CALCIFIC ARTERIAL EMBOLIZATION ACCOMPANYING COMMISSUROTOMY

Report of a Proved Case

Corrado M. Baglio, M.D., and Warren C. Hunter, M.D., Portland, Ore.

MITRAL valvotomy has become a frequent operation since the refinement of the operative technique and the clinical improvement of a great number of patients so treated. However, besides preoperative contraindications, there are certain postoperative complications representing a serious threat to the life of the patient. A complete knowledge of all the possible complicating factors has become very important in order to prevent them. The occurrence of atrial thrombosis, the dislodgment of thrombi and the ensuing peripheral vascular occlusion, with all its consequences, in patients affected by mitral stenosis, has been well known for a period of many years. It is well recognized that dislodgment of atheromatous or calcific plaques from the aorta or other large vessels may account for embolic phenomena. In patients affected by mitral stenosis, there is often severe calcification of the valve orifice, and calcific plaques are frequently formed on the surface of such contracted leaflets. The operative manipulation of the mitral valve can cause sloughing off of calcium particles.

Only a few cases have been reported in the literature of this type of systemic embolism. Attention was first called to calcific arterial embolism by Bailey[1] in 1952. He mentioned having encountered 2 cases. In the same year, Bolton, Maniglia, and Massey[3] gave an unequivocal account of a patient who developed thrombotic embolism of the middle and posterior left cerebral arteries and infarction of the left cerebral hemisphere as a consequence of dislodgment of calcium from the mitral valve. Belcher and Somerville,[2] in 1955, studied 118 cases of systemic embolism in connection with valvotomy. They thought that in 4 cases the accident was due to dislodgment of pieces of calcium from the surface of the valve. However, anatomic proof is lacking in these instances. Ellis,[4] in 1957, gave no anatomic details of his cases of "embolization accompanying mitral commissurotomy," yet occurrence of this type of systemic embolism is widely held. Friedberg[5] in his textbook of *Diseases of the Heart* states that valvular calcification is responsible for embolization at operation. The paucity of fully proved cases in the literature has led us to describe one in which we have demonstrated pieces of calcium from the mitral valve as the agent responsible for cerebral infarction.

From the Department of Pathology, University of Oregon Medical School, Portland, Ore.
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REPORT OF A CASE

Acc. No. A-39-57 (Portland Sanitarium and Hospital). A 42-year-old white woman was admitted to the hospital Aug. 31, 1956, because of the incidental findings of glycosuria and chest pain. She gave a history of shortness of breath for 2 or 3 years. Within the previous 2 years, on two separate occasions, (1) while on a hunting trip, and (2) while carrying her luggage to the railroad station, she had had episodes of sudden constrictive chest pain, severe dyspnea, and had fainted. At the age of 9 years she had had kidney trouble. In 1942, she had had hysterectomy for an unknown type of metrorrhagia. The family history indicated that her mother had diabetes and one brother had died of tuberculosis.

Examination of the heart revealed a normal sinus rhythm. There was a Grade 2-3 systolic murmur heard only at the apex and extending into the left axilla. In diastole, there was a Grade 2 murmur which was heard at the apex and approximately presystolic in nature. The blood sugar was elevated but was easily controlled by insulin and she was discharged from the hospital after 4 days.

On May 12, 1957, she was readmitted to the hospital for surgery for a cardiac lesion, on recommendation of the family physician. She had had two episodes of hemoptysis in the previous 2 months. At this time, she admitted having had St. Vitus' dance from 1924 to 1926, at the age of 16 years.

Physical examination revealed a tall, obese, white woman in no distress. The cardiac rhythm was 125, regular; blood pressure was 138/78 mm. Hg. The chest was clear anteriorly and posteriorly to auscultation and percussion. She had normal tactile fremitus and vesicular breath sounds. The heart size was not determined, due to the patient's obesity. The second sounds were split. P_2 was greater than A_2. There was a Grade 3 systolic harsh murmur heard at the mitral area. No thrills were felt. Examination of other systems yielded no additional information. Electrocardiogram disclosed only a slight depression of the S-T segment, possibly secondary to digitalis effect.

Two days following admission she underwent a mitral commissurotomy. No heart chamber was found to be appreciably enlarged. A 1+ thrill could be felt over the left ventricle, but not over the left atrium. A purse-string suture was placed around the left atrial appendage and the tip was excised. The opening was enlarged to the size of the left index finger which was introduced into the left atrium. The mitral valve measured about 1.3 cm. in length and was very irregular due to marked calcification of both commissures. The calcification did not extend all the way to the mitral annulus. There was a 2½+ diffuse regurgitation. With circulation through the carotid vessels occluded, the anterolateral commissure was easily split, almost at the annulus, with the finger. The posterolateral commissure was opened in a similar manner, using similar precautions, and in several stages. The atrial appendage, the pericardium, and the chest were closed and a drain was inserted into the pleural cavity.

After operation, the patient never regained consciousness, and it became evident that she had suffered a paralysis. There was flaccidity of the extremities and absence of pharyngeal and corneal reflexes. A Babinski reflex was bilaterally present. A tracheostomy was done on the fourth postoperative day but she died shortly, after having been in coma since the operation. The blood sugar, 243 mm. on admission, increased progressively after surgery to a maximum of 500 mm. and was difficult to control by insulin. Microscopic examination of the appendage disclosed the presence of possible fibrillary type of Aschoff bodies.

Pathologic Findings.—The heart was 13 cm. in transverse diameter and weighed 520 grams. There was a slight patency of the foramen ovale but the limbus was overlapping and it was considered as functionally closed. The left atrium was dilated and the amputated appendix was held by black cotton threads, but in the remnant of the atrial appendage there was a red to blackish, adherent clot. The mitral valve was stiff, calcified, and admitted a gloved finger readily. Although the surgeon mentioned splitting both commissures, only one

site of commissurotomy was identified at the posterior commissure. The chordae tendineae were shortened and thickened. There was no evidence of active rheumatic valvulitis or of bacterial endocarditis. The coronary arteries showed a mild grade of arteriosclerosis.

When the dura was reflected there was a great amount of fluid in the subarachnoid space. The vessels composing the circle of Willis showed no evidence of arteriosclerosis. The middle cerebral artery on the right side, just at the site of bifurcation, was blocked by a clot in which was felt a hard mass. In the right hemisphere, there was a large area of softening affecting the posterior part of the frontal lobe, almost all of the parietal lobe, a little of the anterior part of the occipital lobe, and the superior part of the temporal lobe. It extended into both cortex and white matter. On the left side, the softening of the brain covered an area of 4 or 5 cm. in the posterior part of the parietal lobe. On this side, the occlusion responsible for the infarction was not found. No hemorrhage was found anywhere. The pituitary gland contained a yellowish spot which appeared suspicious of infarction.

Fig. 1.—High-power photomicrograph of calcific embolus in right middle cerebral artery. A fibrin and leukocytic thrombus is attached to the calcific fragment along the lower border. (×210; reduced ¼.)

Microscopic Findings.—Sections through the middle cerebral artery and two branches, distal to the point where the hard mass could be felt, revealed an occlusive thrombus formed by layers of fibrin and platelets as well as leukocytes and erythrocytes. Sections of the decalcified middle cerebral artery, at the level where the hard mass was palpated, showed an occlusion of the lumen by two things: (1) the elements of the blood including platelet masses, granulocytes, and erythrocytes and, (2) within this, at the center, a mass of hyalinized and calcified material (Fig. 1). Sections from the cerebral cortex revealed slight necrosis of brain substance (Fig. 2). The whole process was a rather acute one. In the spaces around the blood vessels, there were masses of granulocytic leukocytes. A few small hemorrhages were present. Sections from the wall of the left atrium revealed an ante-mortem clot, old and organized in places and fresh and formed by wavy strands of fibrin, platelets, granulocytes, and erythrocytes in other areas (Fig. 3). No evidence of rheumatic activity or Aschoff bodies was demonstrated in the myocardium. Sections of the pituitary gland revealed a recent area of coagulation necrosis of the anterior lobe with

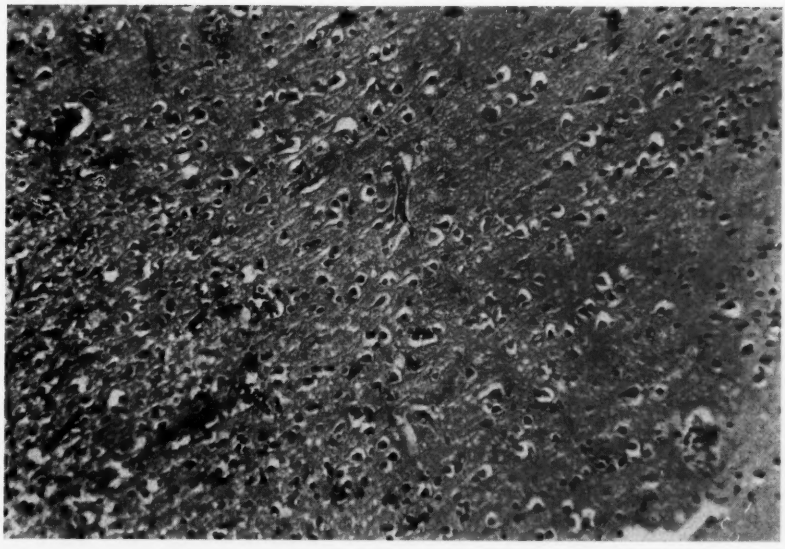

Fig. 2.—Recent necrosis of right parietal lobe of brain is shown along the left border.

Fig. 3.—Recent unorganized mural thrombus of left atrial appendage.

peripheral infiltration of granulocytic leukocytes. Other pertinent findings were: subtotal hysterectomy, salpingectomy, ovariectomy, mild abdominal adhesions, pulmonary edema, congestion and atelectasis of the lungs, fatty metamorphosis of the liver, and atrophy of the islets of Langerhans.

DISCUSSION

After the advent of commissurotomy, attention was called to arterial embolism due to dislodgment of red thrombi from the left appendix. Later, it became evident that the same complication could be produced by freeing of bits of calcium following instrumental fracture of a calcified mitral valve. Technical devices have been adopted by Bailey and his associates[1] in order to reduce the frequency of this risk. In discussing his 20 cases of systemic embolization, occurring during or after operation, Ellis[4] described four factors accompanying arterial embolism in commissurotomy: (1) previous emboli, (2) auricular fibrillation, (3) thrombosis of appendage, and (4) calcific valve. He noticed also that the incidence of embolization increases when more than one factor is present. He stated that, in a total of 20 instances of embolization complicating valvotomy, 5 patients had calcific mitral stenosis as the only factor which could account for embolism. He gave no anatomic account of the type of embolism in such cases. In our case, there are two factors which can be considered as possible complicating phenomena: (1) the presence of red and gray left atrial thrombi, and (2) the calcification of the mitral valve. Histologically, the right cerebral artery, which had no arteriosclerosis at all, contained hyalinized, calcific material and a blood clot which was fresh and must be considered simply as a thrombus formed in situ once the embolic occlusion had occurred. The sections of the artery distal to this point contained a fresh clot, considered as the tail of the thrombus. In such an extensive infarction, we cannot exclude the possibility that the arterial occlusion was due to dislodgment of both atrial thrombi and calcific emboli. However, there is striking evidence that part of the embolus was formed by bits of calcium whose only source is to be considered the mitral commissure at the site where the fracture of the valve was performed. During the operation, before splitting the mitral commissures, the circulation through the carotid arteries was shut off. The patient was also considered to be in good condition postoperatively, even though it was difficult to make a definite statement because she was still under the effect of the anesthetic. It is possible that the embolism occurred within the first few hours following surgery. However, it might have occurred also during the operation and the embolus dislodged into the cerebral vessels through the incompletely closed carotid arteries. We do not know with certainty how great the threat of calcific emboli during or following commissurotomy might be. Probably such kind of emboli are much more frequent than is known, since serious effects occur only on lodgment in a few locations. Anyone who is familiar with fibrocalcific deformities of the mitral valve, in cases of chronic and healed rheumatic disease, knows how friable the calcific material is which is deposited in the mitral cusps and in the annulus fibrosus. We would like to call attention to the fact that such calcific deposits are dystrophic in nature and never become organized,

probably because of the deficiency of blood supply to the valvular leaflets. These deposits are easily sloughed off even with a minimal pressure by the examining finger, once the ring has been cut through or exposed by fracture.

SUMMARY

A case of arterial embolism and ensuing cerebral infarction, related to mitral valvotomy and proved to be the result of dislodgment of pieces of calcium from the calcific mitral ring, has been discussed. A higher incidence of such a complication is probably to be expected, considering the pathogenesis of such a type of embolism, in patients undergoing operative manipulation of a calcific valve of the heart.

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TRAUMATIC VENTRICULAR SEPTAL DEFECT

Report of Two Cases

Gilbert S. Campbell, M.D., Robert Vernier, M.D., Richard L. Varco, M.D., and C. Walton Lillehei, M.D., Minneapolis, Minn.*

THE increased frequency of rapid deceleration accidents, the increased consciousness of possible cardiac trauma, and the successful surgical correction of congenital ventricular septal defects in numerous patients has resulted in a renewed as well as an increased interest in post-traumatic or acquired ventricular septal defects.

The first case in which the diagnosis was established by cardiac catheterization was reported by Guilfoil and Doyle in 1953[1] although, as early as 1847, Hewett reported 5 cases of rupture of the heart and large vessels as a result of injuries.[2] One patient in Hewett's report was a 5-year-old boy who was run over by a heavy cart which passed over his chest and the boy died 30 minutes later. Necropsy revealed a rupture of the ventricular septum at the union of the lower third to the upper two thirds of the septum through which the tip of the little finger could be passed. During the next 50 years other reports of a ruptured ventricular septum appeared and, in 1952, Pollock, Markelz, and Shuey[3] reviewed and reported 12 cases from the literature on this subject and added one case of their own. Other reviews or case reports have also been made.[4-10]

The purpose of this report is to present data on the first case of traumatic ventricular septal defects to be successfully closed surgically.[11] Also, we shall present follow-up information on another patient, the first case of diagnosis by cardiac catheterization,[1] who was subjected to a repeat cardiac catheterization recently at the University of Minnesota Hospitals.

CASE REPORTS

CASE 1.—A 13-year-old Negro boy was seen in the emergency room of the University of Arkansas Hospital on Sept. 11, 1954, with the following note from his referring physician in Pine Bluff, Arkansas: "The above patient (C. R.) was admitted to Davis Hospital on August 16, 1954, following an accident in which he apparently was thrown from an ice truck, striking a bridge. On examination it was found that there was partial atelectasis of the left

From the Departments of Surgery and Pediatrics, University of Minnesota Hospitals, Minneapolis, Minn.

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*Present address: University of Oklahoma Medical Center and Veterans Administration Hospital, Oklahoma City, Okla.

lung and the patient was spitting blood when he coughed. At this time a loud, harsh murmur could be heard all over the precordium and the second sound was faint but clear. His progress was slow but definite improvement was noted and he was discharged 8-25-54 to return to the office, which he did not do until today (9-11-54). At this time he appears to have congestion in both bases, an enlarged liver and an enlarged heart. The murmur has not changed. He is referred for diagnosis and treatment." On this visit to the emergency room he was thought to be in congestive heart failure, with marked cardiomegaly both clinically and radiographically. Unfortunately, he was not admitted to the hospital at this time. However, subsequently he was referred back again on Sept 14, 1954, at which time he was admitted to the Pediatric Service of University of Arkansas Hospital.

Admission History.—The boy (C. R.) was apparently in excellent health until the time of his accident on Aug. 16, 1954. He states that the rear wheel of the truck ran over his chest (although a witness denies this). He attempted to walk away from the scene of the accident but "blacked out" and was unaware of his surroundings until after he had been placed in Davis Hospital, where he remained 9 days. Following termination of hospitalization, he experienced mild orthopnea, mild exertional dyspnea, continued mild hemoptysis, questionable palpitation, and cough. All these symptoms were improving and he stated that he felt better at the time of his admission here than at any time since his accident.

Past History.—There was no history of previous symptoms or signs of rheumatic fever. The patient had had rare bouts of tonsillitis. He had had pneumonia at 2 years of age and he had had mumps and chickenpox. He was well developed, physically being larger than average in both height and muscular development.

Family History.—The patient is the youngest of twelve children. The rest of the history was not revealing.

Admission Physical Examination and Subsequent Course.—The patient was an extremely well-developed and well-nourished boy who was not in acute distress. There were moist râles at both lung bases. The point of maximal impulse was in the sixth left intercostal space at the anterior axillary line. A systolic thrill was palpable over the entire precordium. He had an extremely loud pulmonary second sound. The pulse rate was about 80 per minute, systemic blood pressure was 90/60 mm. Hg, and the respiratory rate 18 to 20 per minute. The liver could not be palpated but there was tenderness and muscle guarding over the liver area. There was a definite hepatojugular reflux. A slight amount of pretibial edema was present and there was distention of the neck veins. The patient could lie flat in bed fairly comfortably. A chest film taken on the day of admission revealed an enlarged cardiopericardial silhouette with evidence of congestive heart failure and minimal right pleural effusion. Hemogram was not remarkable; no anemia, leukocytosis, or elevated sedimentation rate was noted. The initial clinical impression was of rheumatic carditis with congestive heart failure, and the patient was digitalized and placed on a low salt diet. His response was very poor. Mercurial diuretics were relatively ineffective. Cortisone was given over a 2-week period, also, without visible response. In view of the continuing increase in the size of the heart, demonstrated on serial roentgenograms, the poor response to bed rest and digitalization, the persistent lack of anemia or leukocytosis, and an antistreptolysin-0 titer of 50 Todd units, it was thought that rheumatic carditis (which had never been an entirely satisfactory diagnosis) was unlikely and that perhaps traumatic heart disease was a possibility. Serial electrocardiograms had uniformly shown a first degree A-V block (Digitoxin had already been started when the first electrocardiogram was obtained) and persistent Q waves in Leads II, III, and AV_F, consistent with a posterior wall ventricular lesion.

On Nov. 19, 1954, 3 months after the accident, cardiac catheterization was performed and the results are shown in Table I.

The initial chest roentgenograms taken at Pine Bluff, Ark., at the time of the accident showed the cardiopericardial silhouette to be within normal limits as to size and contour.

On March 16, 1955, the patient, 13 years of age and weighing 55 Kg. was admitted to the University of Minnesota Hospitals for surgical correction of his traumatic ventricular

septal defect. The findings described by the University of Arkansas were confirmed and on March 23, 1955, the patient was taken to the operating room. Upon opening the chest through a bilateral anterior thoracotomy (fourth interspace) with transverse sternotomy, numerous adhesions were encountered in the pleural spaces and between the parietal and visceral pericardium. An intense thrill was readily palpable low in the right ventricle. The patient was subjected to total cardiac bypass, utilizing a Sigmamotor pump and biologic membrane oxygenator.[11] Right ventricular cardiotomy revealed a main defect low in the septum near the apex of the heart which was the size of a quarter (measuring about 2.5 cm.). This defect had firm scarred margins unlike any congenital defects seen prior to that time or

TABLE I

SITE	PRESSURE, MM. Hg	OXYGEN CONTENT, VOL. %
Superior vena cava		9.2
Right auricle	+4/–4	8.9
Right ventricle	62/0	14.2
Pulmonary artery	70/24	14.1
Femoral artery		15.5
Systemic blood flow	2.40 L./min.	
Pulmonary blood flow	11.24 L./min.	
Shunt blood flow	8.76 L./min.	

since. There were, in addition, two smaller satellite defects each 3 to 4 mm. in diameter in the immediate neighborhood. These defects were closed with multiple interrupted silk sutures (2-0). The duration of the total cardiopulmonary bypass was 20 minutes. The much enlarged heart immediately became visibly smaller and the thrill disappeared. Extracorporeal flow rates varied between 11 and 18 c.c. per kilogram in this 55 kilogram boy. Upon termination of the cardiopulmonary bypass, the arterial oxygen content was 22.7 volumes per cent, with an arterial blood pH of 7.1. Within an hour, the arterial pH had returned to a normal level as adequate correction of the septal defect with good postoperative circulatory state permitted a rapid and spontaneous correction of the metabolic acidosis by the patient. The patient awoke immediately from anesthesia and following an uncomplicated postoperative course was discharged from the University of Minnesota Hospitals on April 20, 1955.

The boy returned to Arkansas and on Aug. 17, 1955, had a cardiac catheterization performed at the University of Arkansas. The findings are shown in Table II.

TABLE II

SITE	PRESSURE, MM. Hg	OXYGEN CONTENT, VOL. %
Superior vena cava	6/3	15.6
Inferior vena cava	7/5	16.3-15.6
Right atrium	5/2	15.1
Right ventricle	28/0	17.7
Femoral artery		20.6
Systemic blood flow	2.90 L./min.	
Pulmonary blood flow	5.47 L./min.	
Shunt blood flow	2.57 L./min.	

It can be seen that the patient still has a small shunt postoperatively but his pulmonary pressures were now normal and his exercise tolerance has returned to normal. The transverse diameter of his heart was 19 cm. before operation and within 6 months postoperatively the transverse diameter of the heart had decreased to 16 cm. Postoperatively, he was not dyspneic after exercise and showed no signs of cardiac failure. However, there is some dyspnea with prolonged activity such as basketball playing.

CASE 2.—C. T., a 25-year-old ex-soldier was admitted to the University of Minnesota Hospitals on Jan. 9, 1957. He had been in an automobile accident on July 9, 1951, while on

active duty in the armed forces and following this accident a ventricular septal defect was discovered. Catheterization findings of Aug. 29, 1951, have been previously reported[1] and are shown in Table III.

TABLE III

SITE	PRESSURE, MM. Hg		OXYGEN CONTENT, VOL. %
	INSTANTANEOUS	MEAN	
Superior vena cava	-	7	11.2
Right atrium	-	6.5	12.5
Right ventricle	27/6	15	
Right ventricle, mid			14.3
Right ventricle outflow tract			14.9
Pulmonary artery	27/15	21	
Pulmonary artery, main			14.3
Pulmonary artery, left			14.2
Systemic blood flow	6.0 L./min.		
Pulmonary blood flow	16.3 L./min.		
Shunt blood flow	10.3 L./min.		

Repeat cardiac catheterization was carried out at the University of Minnesota Hospitals on Jan. 10, 1957, and these findings are shown in Table IV.

TABLE IV

SITE	PRESSURE, MM. Hg	OXYGEN CONTENT, VOL. %
Superior vena cava		15.3
Right atrium, upper		15.8
Right atrium, mid		16.3
Right atrium, low	2	12.3
Right ventricle, mid	36/4	16.9
Pulmonary artery	14.4	17.8
Femoral artery		19.6
Systemic blood flow	5.9 L./min.	
Pulmonary blood flow	14.1 L./min.	
Shunt blood flow	8.2 L./min.	

It should be noted that the pulmonary artery pressure has not changed since the earlier catheterization 5½ years previously. Heart fluoroscopy revealed a normal transverse diameter, mildly accentuated pulmonary vascularity, and moderate right ventricular enlargement. He was diagnosed as having functional Class I to II heart disease.

DISCUSSION

Two cases of traumatic ventricular septal defect have been reviewed. In the first case the defect was such that the boy showed rather marked pulmonary hypertension with a large left-to-right shunt. This boy was in obvious cardiac failure and surgical closure of this defect was recommended and carried out. Postoperatively the boy has done very well although a small left-to-right shunt is still present. In retrospect, these multiple defects had very rigid and scarred margins (completely unlike the congenital lesions) and doubtless some space-filling substance, such as compressed polyvinyl sponge, should have been placed (as would be done now) between the defect margins to stimulate deposition of connective tissue. However, the fact that the pulmonary pressures had returned to normal within 5 months after operation is ample indication that the residual

leak was small and may close subsequently by deposition of fibrin. Since 3 years have now elapsed, a second postoperative catheterization is planned to test this thesis.

The second case is interesting in that the left-to-right shunt and the pulmonary artery pressure have remained at approximately the same levels as reflected by cardiac catheterization studies which were done 5½ years apart.

For the operated patient (C. R.), although the defects were located low in the muscular portion of the ventricular septum near the apex of the heart, pulmonary hypertension of a rather severe degree had developed rapidly (within 12 weeks), doubtless due to the large size of the shunt. This same situation has been seen a number of times in patients with congenital lesions during the past 4 years and we now know that a ventricular septal defect located low in the septum is not necessarily benign if large in size.

It is possible that most of these traumatic ventricular defects acquired by nonpenetrating trauma to the chest may be located low in the septum since the rupture probably occurs when the exit from the ventricles by way of the aorta or pulmonary artery is effectively occluded by the crushing force.

It is interesting to speculate whether the size and location of the defect in Case 2 may be of such a nature as to be hemodynamically different from congenital ventricular septal defects and from the acquired defects in Case 1. It is conceivable that pulmonary vascular changes may develop during the subsequent years in Case 2, although there is no indication thus far for any progression of the lesion as judged from his cardiac catheterization studies.

Surgical correction has been recommended to this patient as an elective procedure since the risk is now very low (1 to 2 per cent) and will restore the circulation to normal, obviating such potential complications as bacterial endocarditis or subsequent cardiac disability with the passage of time.

SUMMARY

The first patient in whom a traumatic ventricular septal defect has been successfully operated upon has been reported. An extracorporeal pump-oxygenator was utilized for the total cardiopulmonary bypass.

Additionally, a follow-up report, including a recent cardiac catheterization performed at this hospital, is made upon a second patient, of interest as it was the first case in which the diagnosis of a traumatic ventricular septal defect was made by cardiac catheterization.

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MANAGEMENT OF COARCTATION OF THE AORTA IN INFANCY

JD Mortensen, M.D., P. R. Cutler, M.D., W. R. Rumel, M.D., and L. G. Veasy, M.D., Salt Lake City, Utah

THE GENERAL problem of coarctation of the aorta is rather well understood currently by most physicians and surgeons, thanks to the pioneer efforts of Gross,[15, 16, 17] Abbott, [1, 2] Edwards,[5, 12] and others. One phase of the coarctation problem, however, remaining poorly understood, hence controversial, concerns the infant in congestive heart failure associated with coarctation. The points of general agreement relative to such a patient are: first, coarctation of the aorta is a common cause of congestive heart failure occurring in the first year of life; second, when present, coarctation can usually be recognized clinically if considered and looked for in the infant who suffers from congestive failure; and third, congestive heart failure in infants who have coarctation of the aorta constitutes a serious situation with an extremely high mortality.

With this rather dismal note, general agreement and understanding of the problem deteriorates and we are left with considerable question as to the correct answer to such vital questions as: (1) what are the pathologic and physiologic explanations for the development of congestive failure in an infant with coarctation? (2) why is this lesion so difficult to manage successfully? and, (3) what are the best methods of management of a baby with coarctation and congestive heart failure? This communication summarizes our efforts to find answers to these three questions, utilizing two sources: a comprehensive review of medical literature comprising some 234 such case reports and a critical review of our own clinical experience with 20 such cases.

PATHOLOGIC AND PHYSIOLOGIC EXPLANATIONS

It appears evident that a completely satisfactory explanation for the development of congestive heart failure in infants with coarctation is not available in most cases. Obviously, most babies born with coarctation make satisfactory physiologic adjustments to the anomaly in utero or soon after birth, and symptoms only develop later as complications or sequelae from maintaining the abnormal physiologic state for a number of years. The oft-quoted suggestion[5] that postnatal closure of a patent ductus associated with coarctation creates an uncontrollable strain on the left ventricle, because the previously open ductus had prevented the development of sufficient collateral circulation, is effectively challenged by observation that in a considerable number of infants in severe

From the Departments of Thoracic Surgery and Pediatrics, Latter-Day Saints Hospital, Salt Lake City, Utah, and the Rumel Chest Clinic.
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failure the ductus remains widely patent. Furthermore, a number of infants with congestive failure and coarctation have been demonstrated, either at operation or autopsy, to have well-developed collaterals. It seems doubtful, then, that a standard or predictable relationship exists between the degree of collateral circulation, patency of ductus arteriosus, and development of congestive failure in an infant with coarctation.

A factor of considerable significance, however, seems to be the coexistence of other serious cardiovascular anomalies in patients with coarctation. The incidence of associated serious defects in infants with coarctation, who develop congestive heart failure early, seems to be about 40 per cent,[10, 23, 26] while in patients whose coarctation remains asymptomatic until later life only about 15 per cent[2, 16] have serious associated cardiovascular anomalies. The compounding of two or more unphysiologic situations may precipitate congestive failure in early infancy, while a less abnormal physiologic state would permit the cardiovascular system to remain compensated for a longer time.

One would expect the degree of constriction present to play an important role in the ease with which congestive failure develops. However, there is no evidence at present available to indicate that either the narrowness of the constriction or the height of the systolic pressure can be correlated accurately with the time of development of congestive failure. Similarly, it would seem that existence of an anatomically high or long segment of constriction involving the arch of the aorta (the so-called infantile type of coarctation) should be a more serious disorder and cause earlier death. This is probably true. The fact remains, however, that most of the infants with coarctation and congestive heart failure have the short, ductal or postductal (so-called adult type) coarctation and the explanation for cardiac decompensation in such cases is not evident from anatomic observations alone.

A fourth factor that has received little attention in the literature, but in our experience may be important, is the basic biologic and environmental differences in patients. The frequency and severity of respiratory tract infections, the ability of the infant to resist infection, the home environment and hygienic care received, the inherent biologic vigor or toughness of the patient, and such related factors may play an important role in determining just which infant can make the necessary physiologic adjustments to avoid cardiac decompensation while another baby will succumb to heart failure, both having comparable anatomic defects.

REASONS FOR DIFFICULTY IN MANAGEMENT

Satisfactory explanations for the original development of congestive failure, as discussed above, would likewise go far to explain why management of these difficult problems is so often unsatisfactory. Until such understanding is achieved, we will probably be unable to explain fully the extreme difficulty with which these babies are carried through the first year or two of life. It appears evident, both from the literature and our own cases, that respiratory infections constitute particular problems in these babies. More often than not the onset

of infection in the lungs or respiratory passages is accompanied by severe congestive failure. Surely, the respiratory infection makes recognition and management of cardiac decompensation more difficult. Similarly, with the common occurrence of feeding problems, the threat of aspiration, pneumonitis, malnutrition, and failure of proper growth and development the problem of management is further complicated.

An additional factor in this regard is the common failure of parents, as well as pediatric consultants, to maintain adequate digitalization. Once the baby seems to be doing well the tendency to omit the digitalis is ever present. With rapid growth of the child, the maintenance requirements of digitalis may vary considerably. It is well known that re-digitalization is commonly needed and that recurrent episodes of congestive failure will occur rapidly if extreme care and close observation are not carried out in each case.

Mention should be made of the difficulty in some instances in determining accurately the presence of cardiac decompensation in these infants. The clinical signs are not always detected with ease, and the differentiation of physiologic variations due to irritability, crying, or extraneous factors from pathologic signs of congestive failure or respiratory infection may pose real problems. If cardiac decompensation is not recognized and the patient is thought to be ill from pneumonia, digitalization and diuresis may be neglected or postponed. Similarly, if there is respiratory infection which is not recognized because of the preponderance of signs of congestive failure, adequate antibiotic therapy may not be instituted.

DEFINITIVE MANAGEMENT

All agree that the first consideration in an infant who is in congestive failure and has coarctation is the rapid and intensive administration of digitalis, oxygen, and diuretics. Similarly, all agree that ultimately the constricted segment of aorta should be corrected surgically, ideally at age 10 to 14 years. However, the pertinent question remains as to the best method of managing the infant once he has been digitalized, the infection controlled, and the diuresis accomplished. Should the baby be subjected to operation as a means of preventing further episodes of failure and decreasing the hypertension and cardiomegaly or should he be managed medically until 10 years of age before undergoing definitive surgery?

Until recent years, surgical repair of coarctation in infants under one year of age was considered technically impossible. In the last 5 years, however, sufficient experience has accumulated to demonstrate that the operation can be done, the risk is reasonable, and the results, although not perfect, are usually good. During this same period of time, the reports of results from medical management of such cases have changed from extremely pessimistic or hopeless[22, 23, 28] to generally fairly favorable[30] and an occasional optimistic attitude.[19]

Review of the literature up to December, 1957, reveals that 234 cases have been reported of coarctation and congestive heart failure in infants up to one year of age (Table I). In 35 cases, the diagnosis was not made before autopsy

or for some other reason adequate treatment was not given and the patient died. In 134 cases, good medical management was given, including digitalis, antibiotics, and diuretics when indicated. Eighty-seven (64.9 per cent) of these patients died either in the initial or a subsequent episode of congestive failure. Sixty-five babies under one year of age have undergone surgical excision of the coarctation after digitalization had been carried out, with 24 deaths (36.9 per cent mortality).

TABLE I. COLLECTED CASES OF COARCTATION OF AORTA WITH CONGESTIVE FAILURE DURING FIRST YEAR OF LIFE

MANAGEMENT (BIBLIOGRAPHICAL REFERENCES)	CASES REPORTED	DEATHS	MORTALITY (PER CENT)
Not recognized clinically, hence inadequately treated (Ref. 4, 5, 9, 10, 28, 32)	35	35	100
Medical treatment (Ref. 3, 8, 10, 14, 20, 23, 25, 26, 28, 30, 32)	134	87	64.9
Surgical excision of coarctation (Ref. 3, 6, 7, 13, 14, 18, 20, 22, 23, 25, 27, 29, 31, 32)	65	24	36.9
Total Cases Reported	234	146	62.4

In our own experience (Table II) over the past 5 years, we have encountered 20 cases of coarctation in infants under one year of age. Four patients were asymptomatic and did not have congestive heart failure, leaving 16 cases of coarctation and congestive failure in infants up to one year of age. Three were not recognized clinically and the patients died without adequate treatment. Five were treated medically, of which one (20 per cent) died. We have operated on 8 babies with coarctation and congestive failure under one year of age without a death.

TABLE II. TWENTY CASES OF COARCTATION OF AORTA IN INFANTS UNDER ONE YEAR OF AGE

MANAGEMENT	NUMBER OF CASES	DEATHS	MORTALITY (PER CENT)
Not in failure, hence observation without treatment	4	0	0
Not recognized clinically, hence inadequately treated	3	3	100
Medical treatment	5	1	20
Surgical excision of coarctation	8	0	0
Total Cases	20	4	20

These figures, even though they must be viewed with some reservation because of the obvious failings of any such heterogeneous collective review, would seem to indicate that better results are obtained if infants with coarctation and congestive heart failure are treated surgically than by attempting to manage their cardiovascular problems medically for several years until a definitive operation can be done. This conclusion receives additional support by realization

that even if the infant survives on medical management his heart rarely decreases significantly in size and the blood pressure in the arms and head remains elevated, often to a worrisome degree. On the other hand, most infants who have surgical correction experience normal or near normal blood pressure postoperatively and the heart size decreases, often dramatically (Figs. 1 and 2).

The possibility of stenosis at the anastomosis is real when excision is carried out in infants. This is known to have occurred in 7 of the 65 cases from the literature and is suspected in 2 of the 8 infants we have operated upon. It may

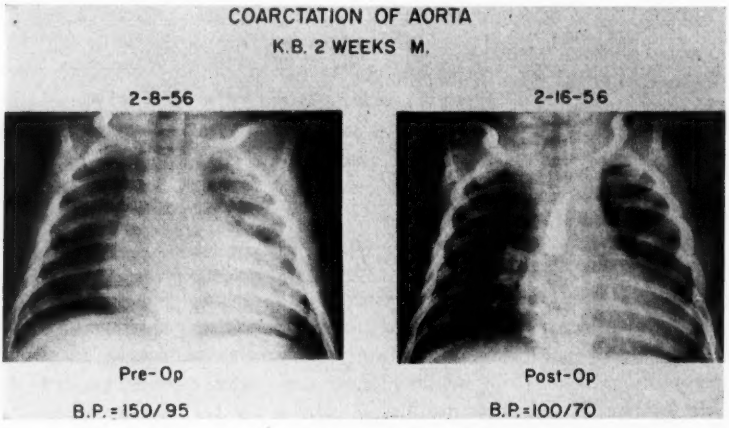

Fig. 1.—Effect of surgical repair on heart size in an infant, 2 weeks of age, in congestive failure with coarctation of the aorta. The preoperative film was taken after the patient had been digitalized. Note the marked decrease in cardiac size one week later, after surgical repair.

be necessary in some of these cases for a second operation to be performed to achieve permanent relief of the aortic stricture, although we have not seen congestive failure redevelop following surgical correction of coarctation, even though a difference in blood pressure (signifying restenosis) between arms and legs may develop.

In reporting 8 operations for coarctation in infants under one year of age without a death, we do not wish to minimize the magnitude and risk of the operation in these tiny infants. There are inherent dangers which must be recognized and dealt with properly or the operative mortality would become prohibitive. First, the operation must be done expeditiously, without tarrying. Infants do not tolerate long procedures well and we feel this procedure should not require more than 2 to 2½ hours if a satisfactory mortality rate is to be achieved. Fluid and electrolyte balance become matters of vital importance in these little patients and must be managed exactly. Respiratory difficulties, including atelectasis, pneumonitis, and laryngeal edema from the endotracheal tube must be prevented or treated vigorously. Technical details are important at the operating table, expert pediatric anesthesia is mandatory, and medical management by an alert pediatrician is essential if this type of surgery is to be accomplished successfully.

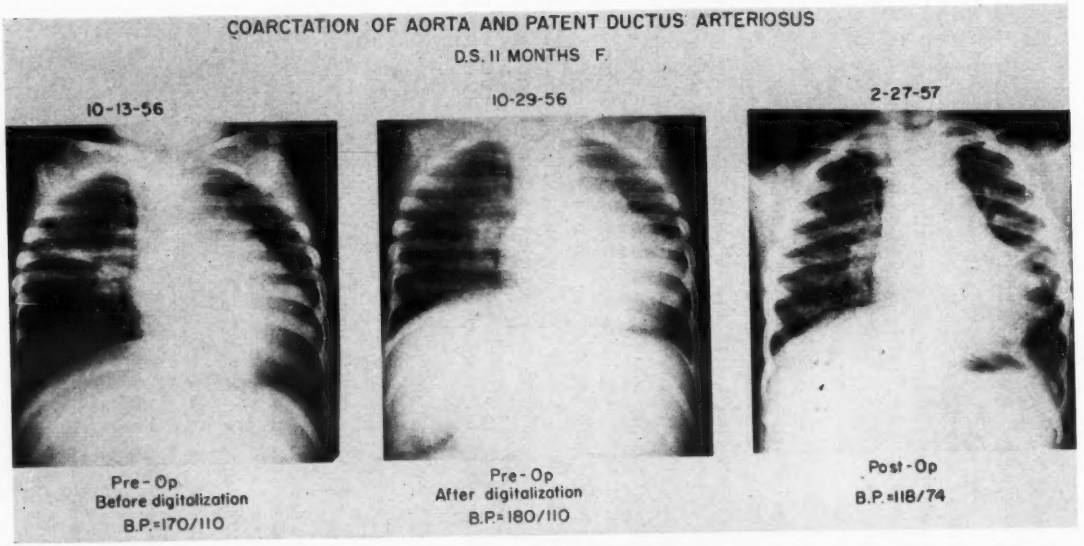

Fig. 2.—Effect of surgical repair of coarctation and patent ductus arteriosus in an 11-month-old patient in recurrent congestive failure. Note that heart size did not change significantly following digitalization, but did decrease following surgical correction. Note also the decrease in pulmonary vascular engorgement following closure of the patent ductus arteriosus.

SUMMARY

Although we frankly admit our conclusions are tentative and may be modified with added experience, our current practice, based on the considerations mentioned above, is as follows: If coarctation of the aorta is discovered in infants who are doing well generally and have no evidence of congestive heart failure, the patient is followed carefully without medication but with close supervision until approximately 8 years of age when surgical excision of the coarctation is carried out. Every infant with evidence of congestive heart failure is examined carefully for signs of coarctation of the aorta. When coarctation is recognized in such an infant in congestive failure, intensive medical management with digitalis, diuretics, and antibiotics, when indicated, is carried out. If clinical response to medical management is excellent, if blood pressure in the arms is under 150 systolic, if the heart is not grossly enlarged after complete digitalization, and if circumstances permit a good long-term medical program with frequent recheck examinations, we will consider deferring definitive surgical treatment until later childhood, the patient being carefully followed on a strict medical regimen. All other infants with coarctation of the aorta who have been in congestive heart failure are considered best treated by surgical excision of the coarctation. Furthermore, if congestive failure recurs in a patient being managed medically, surgical treatment is then recommended. Our present indications for recommending surgical intervention in an infant with coarctation who has been in congestive heart failure are thus summarized as follows (Table III): first, when medical control of decompensation is unsatisfactory; second, when decompensation recurs on a satisfactory medical program; and third, in an occasional patient as an elective measure when poor medical control is anticipated.

TABLE III. INDICATIONS FOR SURGERY IN INFANTS WITH COARCTATION OF AORTA AND CONGESTIVE FAILURE

INDICATION	NUMBER OF CASES
Congestive failure in first month of life, *unsatisfactory medical control* (Operated early, more or less of necessity)	4
Repeated episodes of congestive failure in first year of life; each episode responded to intensive medical regimen *but poor maintenance control* (Operated late, as elective means of maintenance management)	3
Single episode of failure at one month of age, responded well to medical treatment (Operated electively *to prevent further symptoms*)	1
Total Operated Cases	8

CONCLUSIONS

1. Coarctation of the aorta is a common recognizable cause of congestive heart failure during the first year of life.

2. Prognosis of an infant with coarctation who develops congestive failure during the first year of life is rather grave.

3. Under ideal circumstances, certain infants with coarctation of the aorta and congestive failure can be managed by a carefully controlled medical regimen until later childhood when definitive surgical treatment should be carried out.

4. Nevertheless, most infants with coarctation who develop congestive failure during the first year of life will be better managed by surgical repair of the coarctation after adequate medical preparation.

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REPLACEMENT OF THORACIC AORTA WITH ALCOHOL-PRESERVED HOMOGRAFTS

Thomas C. Moore, M.D., and Angelo Riberi, M.D., Indianapolis, Ind.

THE PRESERVED arterial homograft has played an important role in the development of currently employed techniques for arterial replacement and bypass. Although the synthetic arterial prostheses have largely supplanted the use of preserved homografts, considerable clinical interest still exists in the ultimate fate of arterial homografts and in any possible relationship between the method of preservation and this fate.

The suitability of 70 per cent ethyl alcohol for the sterilization and preservation of homografts in experimental small artery replacement was reported by the authors in 1956.[2] The results with alcohol preservation were comparable with those encountered when freeze-drying techniques were employed. Except for the study of Kimoto and his associates[1] in 1954, relatively little has been published in recent years relative to the use of alcohol for homograft preservation and sterilization.

The purpose of this report is to record the results of the experimental use of alcohol-preserved homografts of aorta for replacement of proximal descending thoracic aorta. The gross and microscopic appearance of the homografts was studied at varying intervals, from one day to one year, after placement. The replaced segment of thoracic aorta was utilized to replace a section of the animal's superior vena cava. The suitability of the fresh autogenous aorta, thus obtained, for superior vena caval replacement has been reported in greater detail elsewhere.[3]

MATERIAL AND METHODS

Healthy mongrel dogs were used. The weight of the dogs ranged from 12 to 23 Kg. A mixture of oxygen and ether, delivered through an endotracheal tube by means of a mechanical respirator, was employed for anesthesia following induction with intravenous Pentothal. Hypothermia was achieved by immersion of the anesthetized and intubated dog in an ice water bath. The body temperature generally was lowered to approximately 31° C.

From the Department of Surgery, Indiana University Medical Center, Indianapolis, Ind.

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A left thoracotomy was carried out through the fourth or fifth intercostal space. The more cephalad portion of the descending thoracic aorta was dissected free from surrounding structures. The intercostal arteries in this area were divided between ligatures. The aorta was occluded with Potts coarctation clamps above and below the sites of proposed transection. The isolated segment of aorta was resected. The resected section of aorta generally measured between 6 and 8 cm. in length. The resected aorta was replaced with an alcohol-preserved aortic homograft of approximately the same length. The duration of homograft storage and preservation in 70 per cent ethyl alcohol ranged from 6 to 21 days. The alcohol-preserved homografts were reconstituted for one hour prior to use in a normal salt solution containing streptomycin and penicillin. The anastomoses were carried out with a continuous over-and-over 5-0 arterial silk suture. In all of the animals, the homograft appeared to function satisfactorily on completion of the anastomoses and removal of the occluding Potts clamps. The homograft was covered with adjacent pleura and the left chest was closed in layers. A catheter was left in the left chest for subsequent aspiration.

The resected segment of aorta was used to replace a segment of superior vena cava through a right thoracotomy. Following this procedure, the dog's temperature was returned to normal by immersion in a warm water bath. Upon completion of the rewarming, both chest catheters were aspirated and withdrawn. Penicillin was given for 4 days following operation.

RESULTS

The proximal descending thoracic aorta was resected and replaced with an alcohol-preserved aortic homograft as described in 31 dogs. The patency and the gross and microscopic appearance of the homograft were investigated in all animals on postmortem examination from one day to one year following operation.

The homograft had remained patent in all of the animals (Table I). In only one animal was there a significant reduction in the size of the lumen. In this animal (Dog 821), a large thrombus on the wall of the graft had produced a 30 per cent reduction in the lumen of the graft 3 months following operation. Although the periods of alcohol storage were relatively short, there was no apparent affect of the period of preservation on the ultimate fate of the homograft. There was no evidence of homograft-induced infection.

The duration of homograft placement seemed to be the most important factor in the fate of the grafts. Little significant change was encountered in the gross appearance of the homograft during the first month after operation. However, in the interval from 1 to 4 months, gross alterations in the graft were found to occur in a high per cent of the animals. The principal changes were those of intimal roughening and erosion and thrombus formation. A different type of gross change was found in animals sacrificed between 11

TABLE I. SUMMARY OF RESULTS OF EXPERIMENTAL USE OF ALCOHOL-PRESERVED HOMOGRAFTS OF AORTA FOR REPLACEMENT OF THORACIC AORTA

DOG NO.	INTERVAL OPERATION TO AUTOPSY	PERIOD OF HOMOGRAFT STORAGE IN ALCOHOL (DAYS)	GRAFT PATENCY	REMARKS
806	1 day	9	Patent	
836	1 day	21	Patent	
838	1 day	9	Patent	
845	1 day	9	Patent	
855	1 day	9	Patent	
824	2 days	10	Patent	
822	3 days	9	Patent	
876	5 days	6	Patent	
895	5 days	6	Patent	
808	7 days	9	Patent	
843	7 days	13	Patent	
888	8 days	14	Patent	
839	12 days	9	Patent	
825	14 days	21	Patent	
812	30 days	15	Patent	
817	33 days	11	Patent	Intimal roughening
853	34 days	16	Patent	Intimal roughening with areas of thrombosis
887	34 days	14	Patent	Thrombus on graft wall
855	37 days	16	Patent	
831	2 mo.	16	Patent	Intimal roughening with areas of thrombus formation
842	2 mo.	9	Patent	Thrombus on graft wall
871	3 mo.	12	Patent	Intimal roughening with areas of thrombus formation
787	3 mo.	11	Patent	
821	3 mo.	6	Patent	Large thrombus on wall with reduction in size of lumen
813	4 mo.	15	Patent	Intimal roughening with areas of thrombus formation
828	7 mo.	15	Patent	
851	11 mo.	6	Patent	
862	11 mo.	16	Patent	Extensive calcification of graft with early aneurysm formation
872	11 mo.	12	Patent	Areas of graft calcification
826	12 mo.	15	Patent	Extensive atheromatous degeneration with dilatation of graft
827	12 mo.	15	Patent	Areas of graft calcification

and 12 months following operation. Atheromatous degeneration, calcification, and graft dilatation were the gross alterations discovered in 4 of the 5 animals in this group (Fig. 1).

It is of interest that the resected segment of fresh autogenous aorta which was used for superior vena caval replacement had not only remained patent in all of the animals but also had remained free of degenerative changes, calcification, fibrotic narrowing, dilatation, and thrombus formation in all. To illustrate this observation, it may be noted that the gross appearance of the fresh autograft of aorta in the critical area of superior vena caval grafting contrasts sharply with the appearance of the alcohol-preserved homograft of aorta utilized in the less critical area of aortic replacement in the same animal (Dog 862) one year after operation (Fig. 2).

Microscopic study of the homografts revealed rather constant findings. The grafts remained acellular and relatively amorphous. The amorphous

appearance increased with the passage of time and was associated with a significant decrease in the thickness of the graft wall (Fig. 3). There was no evidence, in any of the sections studied, of significant vascular or cellular ingrowth into the homograft, either from the host artery at the site of anastomosis or from the living host tissues adjacent to the outer wall of the graft (Fig. 4).

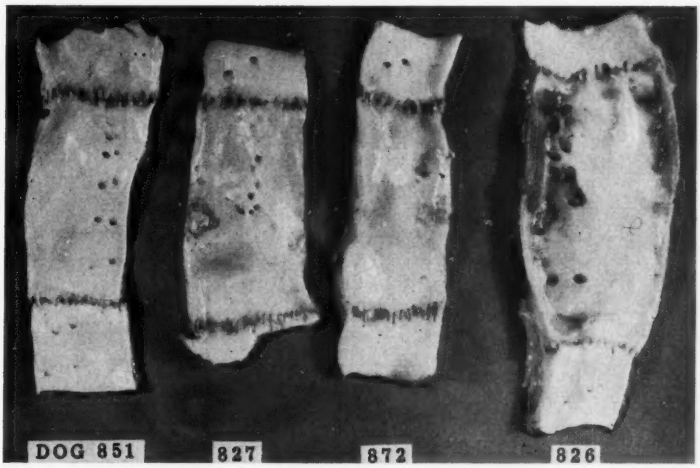

Fig. 1.—Photograph showing the appearance of four alcohol-preserved aortic homografts used to replace resected segments of thoracic aorta at autopsy, 11 and 12 months after operation.

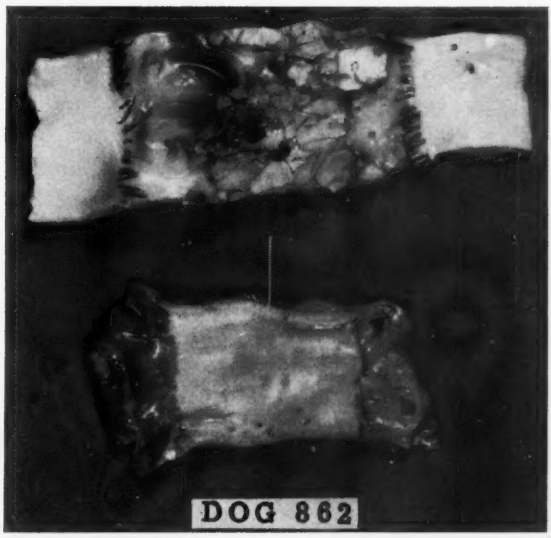

Fig. 2.—Photograph of aortic homograft used for aortic replacement (*above*) and aortic autograft used for superior vena caval replacement (*below*) in same animal 11 months following operation. The extensive calcification and aneurysmal dilatation of the homograft are in marked contrast to the normal appearance of the autograft.

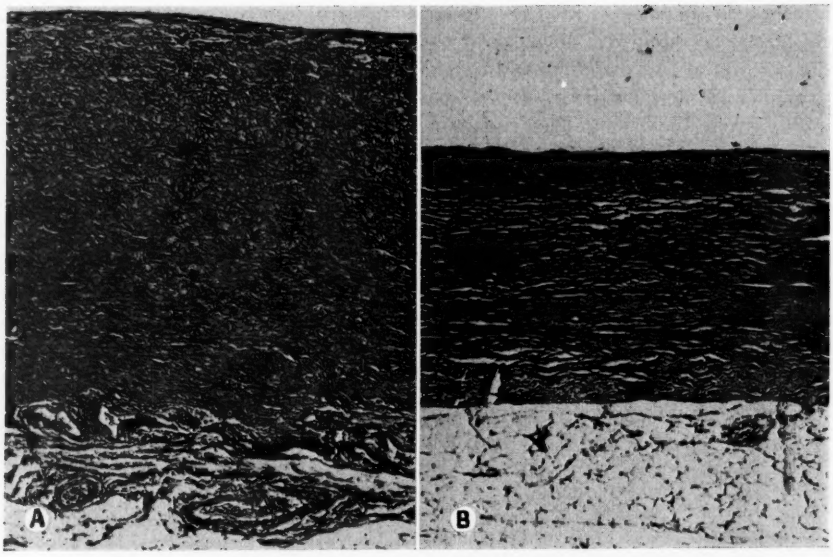

Fig. 3.—Photomicrographs, at the same magnification, illustrating the degree of homograft thinning (*B*) in comparison with adjacent normal host aorta (*A*), 12 months after graft placement.

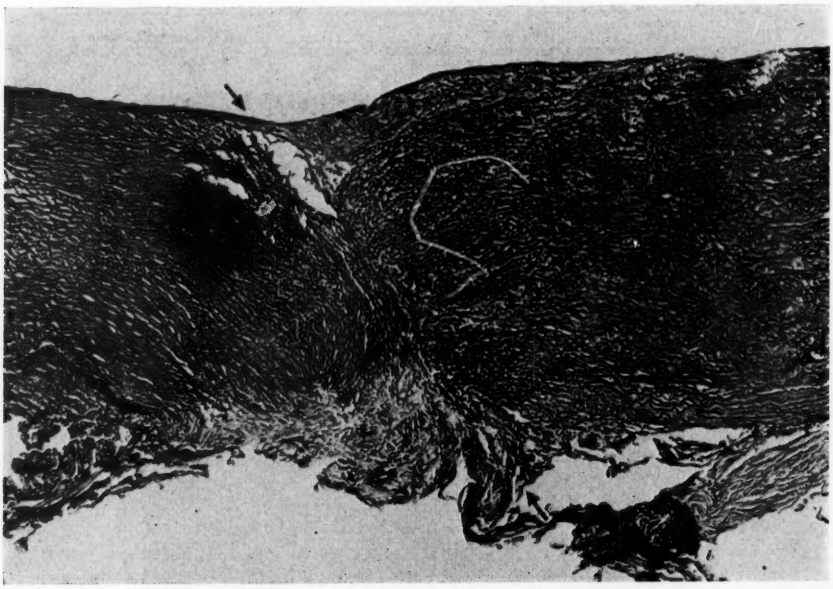

Fig. 4.—Photomicrograph showing junction line (*arrows*) between homograft (*left*) and host aorta (*right*), 12 months after operation. There is no vascular or cellular ingrowth into the homograft from either the host aorta or adjacent host connective tissue.

DISCUSSION

The observation in this study that all 31 alcohol-preserved aortic homografts remained patent in the thoracic aorta from one day to one year after placement suggests that the alcohol method of preserving aortic homografts may be, at least, as suitable as the freeze-drying method. The period of time the grafts were stored in alcohol, within the limits of this study, did not appear to affect the fate of the grafts. Similar findings were recorded by Kimoto and his associates[1] in 1954. They employed both 70 per cent ethyl alcohol and pure ethyl alcohol for aortic homograft preservation and utilized periods of graft storage in these concentrations of alcohol ranging from 9 to 269 days. An analysis of their reported results reveals the two concentrations of alcohol to be equally effective. The period of storage in their study did not appear to be a factor in the success or failure of the graft with respect to the retention of patency. Twenty of the 22 alcohol-preserved aortic homografts used by them for aortic replacement remained patent. Only 6 of their animals were followed in excess of 100 days.

While retention of graft patency does not seem to be a problem in the replacement of segments of thoracic aorta with homografts, the occurrence of degenerative changes with the passage of time does pose some real problems. These degenerative changes include calcification, thinning and dilatation of the graft. The relatively amorphous, acellular character of the graft and its apparent "sequestration" from surrounding host tissues, with the absence of host vascular and cellular ingrowth, were regarded as significant factors in the development of these changes. Szilagyi and his associates[4] have recently reported similar disturbing changes in human arterial homografts.

The degenerative homograft changes encountered in this study fell into three rather distinct periods. Little alteration in the gross appearance of the graft was found in the first month after operation, whereas grafts examined between 1 and 4 months after placement showed a high incidence of intimal erosion and ulceration and thrombus formation. These changes were not encountered in grafts examined 11 and 12 months following operation. In these grafts, the significant degenerative changes were those of graft thinning with localized or general dilatation, atheromatous plaque formation, and calcification.

An unusual opportunity was offered in this study to compare the fate of free grafts of fresh autogenous aorta and that of preserved homografts of aorta when both types of graft were used for vascular replacement in the same animal. The fresh autografts were employed with success in the superior vena cava, a critical area for vascular replacement where homografts of aorta have been shown to be unsuitable. The fresh autograft, with its structure and cells intact, remained a part of the living organism and its superiority was indicated by its freedom from the progressive degenerative changes which afflicted the great majority of the alcohol-preserved homografts.

SUMMARY

The use of alcohol-preserved homografts of aorta for the replacement of 6 to 8 cm. resected segments of proximal descending thoracic aorta in 31 dogs is reported. In all animals, the homograft was patent at the time of postmortem examination, from one day to one year after operation. Despite this satisfactory retention of graft patency, a number of disturbing degenerative changes were discovered in a large per cent of grafts examined over one month after placement. Intimal erosion and ulceration with thrombus formation were encountered in the early months after operation, while graft thinning and dilatation with calcification and atheromatous plaque formation occurred later. There was no microscopic evidence of vascular or cellular ingrowth in any of the grafts studied and the homografts appeared to be, in effect, "sequestered" from the host organism. The fate of the alcohol-preserved aortic homograft in the thoracic aorta is compared with that of the free graft of fresh autogenous aorta used for superior vena caval replacement in the same animal.

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STUDIES OF THE CORONARY CIRCULATION

I. The Surgical Anatomy of the Right Coronary Artery of the Dog and the Effects of Acute Ligation

Knut Haeger, M.D., Malmö, Sweden*

THE ANATOMY of the coronary arteries in the dog has been studied by several authors.[2, 6, 7, 9, 12] These authors generally agree that the right coronary artery arises from the aorta near the right anterior cusp, and runs in the atrioventricular groove where it bifurcates into two main branches. One branch runs along the anterior portion of the right ventricle and the margo acutus. The other runs to the posterior part of the right side of the heart. Pianetto[9] states the external diameter of the main stem of the artery is between 1.0 and 1.5 mm.

Acute ligation of the right coronary artery generally causes severe trouble. Porter[10] ligated the right coronary artery in 11 dogs and observed cardiac standstill. In 2 animals, cardiac standstill was followed by ventricular fibrillation. The ultimate fate of the dogs surviving the acute insult was not reported by the author. Cohnheim and von Schultess-Reichberg[1] regularly observed ventricular fibrillation after the ligation of either of the two major coronary arteries. Smith[11] ligated the right coronary artery of 8 dogs. He noted four immediate and three late deaths; one animal survived in excellent condition. Parade[8] ligated the artery of 5 dogs; one died of ventricular fibrillation, and the other 4 died within 48 hours. Donald and Essex[2] ligated the right artery in 21 dogs; 5 of these died within 48 hours after the operation. However, 16 of their dogs survived in good condition. The wide variation in the incidence of ventricular fibrillation and early death found in the above papers is probably explained by a recent report by Milch and his associates.[5] These authors reported that, following ligation of a major coronary artery, any slight somatic stimulation readily induced ventricular fibrillation. Also, Garamella and co-workers[3] stress the many variables of acute ligation of a coronary artery and the different results that may be obtained by different operators.

The purpose of the present report is twofold. We wish to describe what is apparently a common variant of the classical description of the extramural

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*Halsted Fellow at the University of Colorado School of Medicine, Denver, Colo., from the Department of Experimental Surgery, Allmanna Sjukhuset, Malmö, Sweden.

distribution of the right coronary artery. In addition, we wish to demonstrate the consequence of this anatomic variation on the effect of acute ligation of the right coronary artery and some of its branches.

METHOD

This report includes observations on 90 dogs; 83 were mongrels and 7 were trained greyhounds. All animals were anesthesized with intravenous Nembutal in a dosage of approximately 30 mg. per kilogram and were artificially respired with oxygen by means of an automatic, intermittent positive pressure respirator. All operations were performed under completely aseptic conditions. The chest was entered by way of right thoracotomy at the level of the fourth or fifth interspace. After slitting the pericardial sac, the extramural anatomy of the right coronary artery was noted. Any variant from the classical description of this vessel was sketched immediately following surgery.

After tracing the course of the right coronary artery, either the main stem itself or one or more of its branches was ligated. Since these experiments were undertaken as a control to other experiments involving the insertion of a plastic tube into the right coronary artery, those animals subjected to ligation of the main branch of the right coronary artery were also subjected to manipulations simulating the insertion of a plastic tube into the artery. We have called this a sham operation.

Following this procedure the animal was watched for a short period of time to see whether early ventricular fibrillation developed. The thoracotomy was closed, and the animal was given supportive postoperative care. Only those animals surviving in good health for periods of longer than 7 days were included as survivors. Those animals succumbing to late death were autopsied to determine presence or absence of myocardial infarction.

RESULTS AND DISCUSSION

The Anatomy of the Right Coronary Artery.—As a rule, the distribution of the right coronary artery was found to be in complete agreement with the observations of the authors just quoted. In most of the animals, the branches were distributed as shown in Fig. 1 and diagrammatically in Fig. 2, *A*. The two dominant branches of the artery are the ramus marginalis acuti (No. 5 in Fig. 2) and the ramus circumflexus dexter (No. 7 in Fig. 2). In some dogs, however, the ramus ventriculi dexter anterior (No. 4 in Fig. 2) was very well developed, whereas the ramus marginalis acuti was less pronounced. This distribution is depicted in Fig. 2, *B*. Table I shows that, of the 83 mongrel dogs observed, the ramus ventriculi dexter anterior was the dominant anterior branch of the right ventricle in only three instances. However, this was the dominant anterior branch in all 7 of the greyhounds observed. This difference in right coronary distribution, greyhound versus classical, has certain surgical implications which shall be discussed later.

TABLE I. DOMINANT ANTERIOR BRANCH OF THE RIGHT CORONARY ARTERY OF THE DOG

"SPECIES"	NUMBER	DOMINANT ANTERIOR BRANCH	
		RAMUS MARGINALIS ACUTI	RAMUS VENTRICULI DEXTER ANTERIOR
Mongrels	83	80	3
Greyhounds	7	0	7
Totals	90	80	10

In most of the dogs observed, the diameter of the main stem of the right coronary artery was within the limits stated by Pianetto.[9] In some dogs, however, the external diameter of the artery was found to exceed 2 mm. and, in a few cases, a plastic tube with an outside diameter of 2.43 mm. could be easily threaded into the lumen.

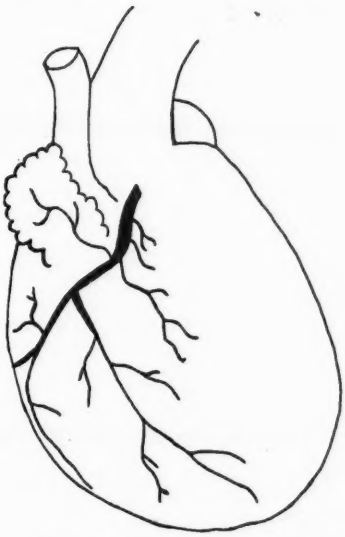

Fig. 1.—The normal anatomy of the right coronary artery in the dog. The right auricular appendage is turned upward to expose the proximal part of the artery.

The Effects of Acute Ligation of the Right Coronary Artery.—The results of 16 sham operations, including complete acute ligation of the right coronary artery, are shown in Table II. Thus, in this series, 15 out of 16 dogs died within the first 24 hours after ligation, and in 4 of the 5 animals surviving the operation, right myocardial infarction was present at autopsy.

TABLE II. RESULTS OF SHAM OPERATION INCLUDING TOTAL ACUTE LIGATION OF THE RIGHT CORONARY ARTERY

FATE OF THE DOG	NUMBER OF DOGS
Ventricular fibrillation	11
Died within 24 hours	4
Survival	1

During the course of our experiments, it was observed that no harm followed ligation of the smaller branches originating from the proximal end of

the artery (Nos. 2, 3, and 10 in Fig. 2). Branch No. 2 was ligated five times, No. 3 was ligated in 60 dogs, and No. 10 in 40 dogs. In no instance did these ligations result in alteration of cardiac rhythm or in the development of myocardial infarction.

The procedure for placing a tube in the right coronary artery, to be described in a subsequent paper,[4] requires ligation of the ramus ventriculi dexter anterior (No. 4 in Fig. 2). This vessel was ligated in 80 animals in which the dominant anterior branch was the ramus marginalis acuti. In none of these animals was there either a disturbance of heart rhythm or gross signs of myocardial infarction noted. In the greyhounds, however, where this branch was extremely well developed and probably supplied a comparatively large part of the wall of the right ventricle, ligation of this branch caused

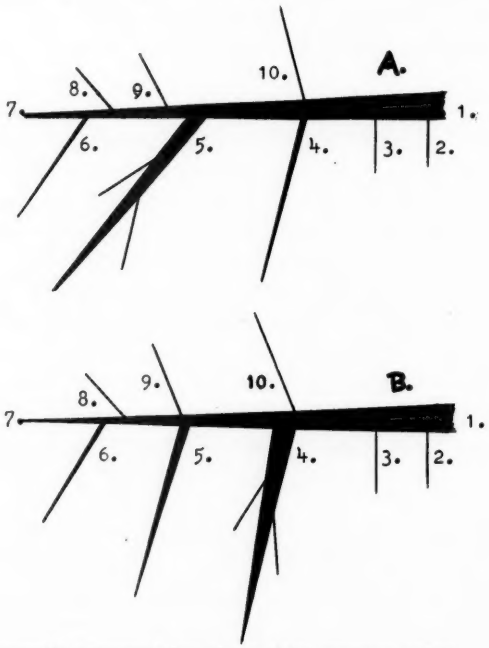

Fig. 2.—Diagrammatic representation of the right coronary artery.
A, Normal dog.
B, Dogs with "greyhound" anatomy.
1—Art. coronaria cordis dexter; *2* and *3*—Small branches; *4*—R. ventriculi dexter anterior; *5*—R. marginalis acuti; *6*—R. ventriculi dexter posterior; *7*—R. circumflexus dexter; *8* and *9*—Small branches; *10*—R. atrialis dexter anterior.

either immediate ventricular fibrillation or subsequent myocardial infarction in the area supplied by this vessel. Thus, in all dogs with the typical "greyhound anatomy," ligation of the ramus ventriculi dexter anterior resulted in ventricular fibrillation or early postoperative death from myocardial infarction; whereas ligation of the same branch in dogs with the classical described anatomy of the right coronary artery caused no harm.

CONCLUSION

Observations on the anatomy of the right coronary artery of 90 dogs confirmed the findings of earlier authors. In some dogs, however, notably the trained greyhound, the ramus ventriculi dexter anterior is the dominant anterior branch of the right coronary artery rather than the ramus marginalis acuti. In those dogs with "greyhound" anatomy, ligation of the ramus ventriculi dexter anterior uniformly resulted in death.

Under the conditions of these experiments, acute ligation of the main stem of the right coronary artery resulted in ventricular fibrillation or death by myocardial infarction in 15 of 16 dogs. No detrimental effect was noted following ligation of the three branches of the right coronary artery that arise proximal to the ramus ventriculi dexter anterior.

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STUDIES OF THE CORONARY CIRCULATION

II. Nylon and Polyethylene Tubes as Coronary Artery Prostheses

Knut Haeger, M.D., Malmö, Sweden, Georg R. Wallgren, M.D.,** Helsingfors, Finland, and Peter Dundas, M.D.,*** Denver, Colo.*

DURING the past few years many nonbiologic materials have been used as replacements in peripheral artery disease. As a rule, the initial results of the operations have been fair; however, all types of grafts have shown a high incidence of late thrombosis or, in some cases, rupture of the graft. Recent results with the Edwards-Tapp chemically-treated nylon prosthesis seem to be better than with other materials.[3, 5] On the other hand, it was recently stated that plastic materials nearly always fail in small arteries.[12]

In attempts to revascularize the ischemic myocardium, several surgical procedures have been tried. As yet, however, none of these have been generally accepted. Recently, some work was published on the utilization of plastic material tubes for the revascularization of the heart. Smith and coworkers[20] connected the aorta with the myocardium by means of a 4.5 mm. diameter nylon tube and reported good anatomic and functional results with roentgenologic evidence that the tube remained open. Massimo and Boffi[11] created an anastomosis between the cavity of the left ventricle and the myocardium in dogs by means of a polyethylene T-tube with successful results in 32 experiments. In a preliminary report of this study,[6] it was stated that a polyethylene tube inserted as a bridge in the resected right coronary artery stayed open at least 9 months after the operation, and contrast medium injected in the root of the aorta in the living dog could be demonstrated distal to the graft.

Attempts have been made to direct the blood flow from systemic arteries to the distal parts of the occluded coronary arteries. Thus, as early as in 1940, Murray[13] reported on successful coronary artery anastomoses from the internal mammary artery in dogs. Thal and associates,[23] using a temporary

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*Halsted Fellow, University of Colorado School of Medicine, Denver, Colo., from the Dept. of Experimental Surgery, Allmänna Sjukhuset, Malmö, Sweden.

**Foreign Exchange Student of the Institute of International Education from Helsingfors, Finland.

***Halsted Fellow, University of Colorado School of Medicine, Denver, Colo., from Oslo, Norway.

coronary perfusion via a plastic cannula, made an end-to-end internal mammary to coronary artery anastomosis in dogs. With coronary arteriography, they were able to demonstrate the anastomosis to be patent in 7 dogs out of 17 after an observation time of 2 to 6½ months.

In the present study, an attempt has been made to evaluate experimentally the fate of polyethylene and nylon tubing replacements of the right coronary artery of the dog.

OPERATIVE TECHNIQUE

Mongrel dogs, varying in weight from 14 to 40 Kg., were used. The dogs were anesthetized with intravenous pentobarbital sodium (30-40 mg. per kilogram of body weight) and, after tracheal intubation, artificially controlled respiration using 100 per cent oxygen was maintained. The right side of the heart was exposed by right-sided thoracotomy with the subject in the left lateral position. To some of the dogs procaine amide (Pronestyl*) was given in intravenous dextran infusion; in other experiments the dogs were infused with 5 per cent glucose in saline.

The right coronary artery was dissected from approximately 10 mm. distal to its origin in the aorta to the main bifurcation of the right ramus marginalis acuti and the ramus circumflexus dexter. The smaller branches leaving this area were ligated and severed. This procedure permits 10 to 20 mm. of the artery to be completely loosened from the fatty auriculo-ventricular groove. The artery was ligated and the time noted. A hole was cut distal to the ligature and a tube of polyethylene or nylon was inserted and doubly ligated with 3-0 silk. Two types of tubing were alternately used: (1) polyethylene (Intramedic†) and (2) nylon.‡ The diameter of the tube was selected so that the inner diameter would be as close to the original vessel inner diameter as possible. Sizes from 0.97 mm. to 2.43 mm. (external diameter) were used. The tube was filled by blood from the distal part of the artery by the reverse flow. In the first series of operations a small piece (15 to 20 mm.) of the tube was threaded directly into another hole cut proximal to the ligature (Fig. 1, *A*). In the second series, the tube (120 to 140 mm.) was formed into a loop with an approximate inner diameter of 15 to 25 mm., and the other end threaded into the proximal hole. Also, the proximal part of the tube was secured in the artery by 3-0 silk (Fig. 1, *B*). In a third series of dogs, the internal mammary artery was dissected to 10 to 15 mm. from its origin and divided so that a 30 to 40 mm. free proximal stump was obtained. The artery was then transposed to the mediastinal side of the pleural cavity and secured with 3-0 silk stitches. A nylon or polyethylene tube (130 to 150 mm.), filled with heparinized saline, was inserted into this stump and secured with two or three 3-0 silk stitches. The distal end of the

*E. R. Squibb & Sons, New York, N. Y.
†Clay-Adams Company, Inc., New York, N. Y.
‡Thermoglas, Inc., Gothenburg, Sweden.

tube was inserted in a hole cut distal to the ligature on the right coronary artery and the blood flow released.

During the insertion of the tube into the proximal part of the coronary artery in Series 1 and 2, the blood flow was occluded by means of a loose ligature or by a micro-bulldog clamp. After the tube had been secured, the temporary occlusion was released and the blood could be seen passing from the proximal part of the artery to the dital part, by passing the ligated part.

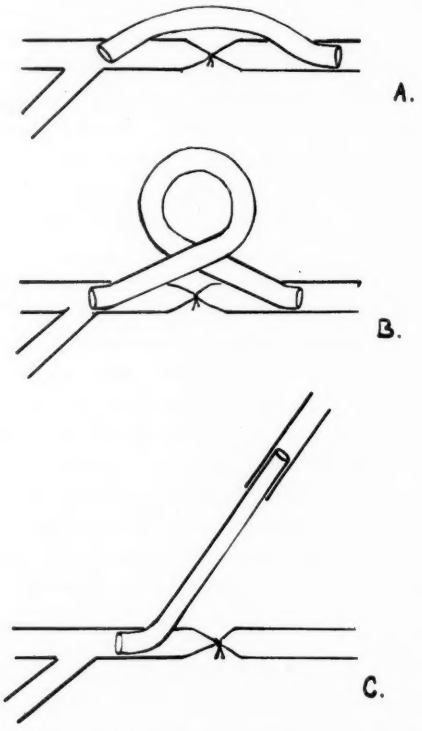

Fig. 1.—Semidiagrammatic representation of three different methods of bypassing the occluded area of a coronary artery with plastic tubes.

The pericardium was not closed in the first series of dogs. If the loop technique was used, the cranial part of the pericardium was closed over the loop with a few stitches. In some cases, the loop also had to be secured to the heart by a 5-0 silk stitch in the wall of the right auricle or auricular appendage. If the internal mammary artery technique was used, the bridging part of the tube was covered by pericardium and pleural tissue.

The thoracic cavity was closed and the dog remained on the table with artificial respiration of 100 per cent oxygen for one or 2 hours after the operation.

RESULTS

The 17 dogs first operated upon in these series were reported earlier.[6] For clarity, they have been included in the present series. A survey of all dogs operated upon with the direct method is presented in Fig. 2.

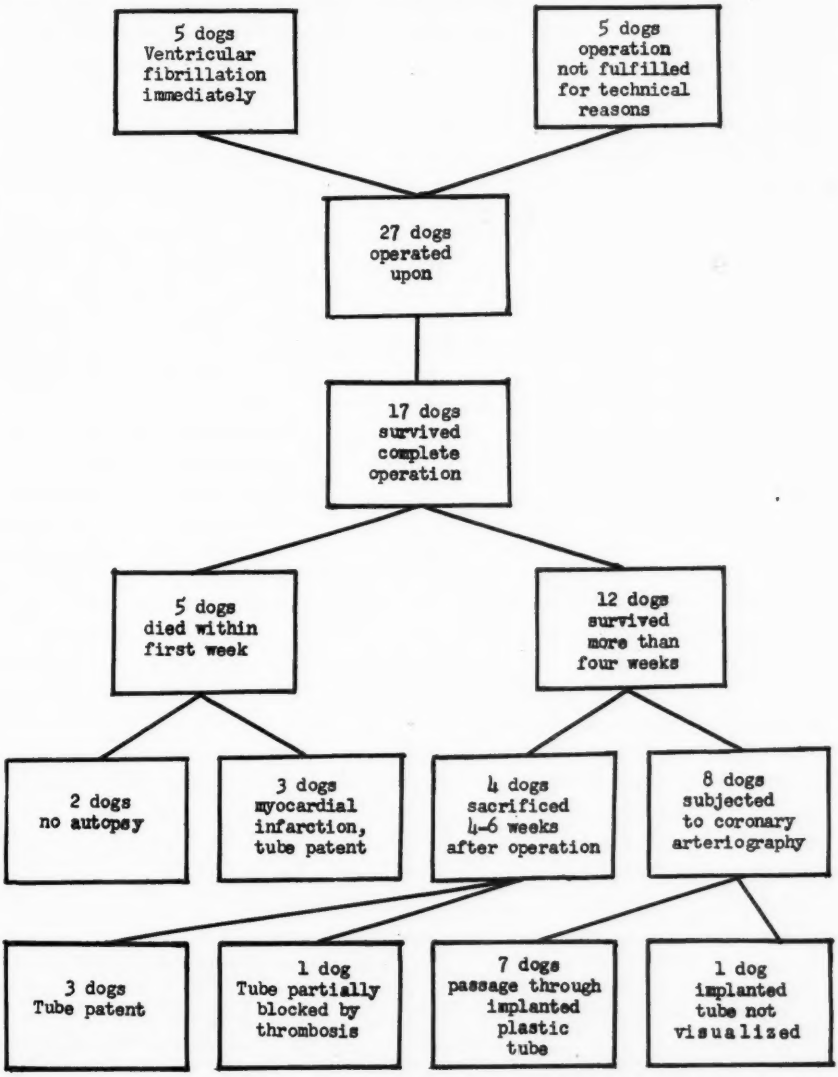

Fig. 2.—The fate of 27 dogs subjected to direct implantation of a plastic tube in the right coronary artery.

a. *Direct Method.*—With the direct method (short piece of tubing), 27 dogs were operated upon. In 5 dogs, the coronary vessels were found to be

too small, and it was technically impossible to insert even a minimum size tube. In 4 of these dogs polyethylene tubing was tried, and in one, nylon tubing. All four polyethylene tube trials were done in the beginning of the series on small dogs. After this experience, only dogs weighing more than 18 Kg. were used, except one smaller dog in which the stiffer nylon tube was tried without success. In all of these 5 dogs, the right coronary artery was left ligated. After a short while, signs of myocardial hypoxemia were evident, and all 5 dogs died within the first few hours after the operation.

Five dogs died from ventricular fibrillation shortly after the tube had been put in place. The total time of occlusion of the blood supply to the right myocardium in these cases was 4, 5, 6, 7, and 8 minutes, respectively. In some cases, antifibrillatory treatment was used. As could be expected, however, all efforts to restore normal rhythm were in vain.

Seventeen dogs survived the operation. Another 4 deaths occurred within the first 24 hours, and one dog died after 6 days. Unfortunately, 2 of these dogs were not examined postmortem. In the 3 remaining dogs, there were signs of gross myocardial infarction in the right half of the heart. The tubes were found to be patent without evidence of thrombosis in all 3 cases, and the myocardial damage, therefore, probably occurred during the operative procedure with occlusion of the artery.

Of the remaining 12 dogs, 4 were sacrificed 4 to 6 weeks after the operation. In 3 of these cases the tube was found to be completely patent and the passage of blood through the tube to the peripheral branches of the artery unhindered as indicated by injection of India ink through the coronary ostium. Microscopically, there were no signs of infarction in the myocardium supplied by this artery. In one dog there was a small clot partially obstructing the free flow of blood through the lumen. There was, however, no sign of myocardial infarction in this dog.

Eight dogs are still alive in perfect condition. The time of observation varies between 5 and 18 months. These dogs were submitted to coronary angiography one to 3 months after the operation. In all cases but one the bypassing tube could be visualized and the vessels distal to the tube were filled with contrast medium. In one dog, the right coronary artery, including the polyethylene graft, could not be visualized and the possibility of the tube being occluded cannot be excluded. Thus, in 12 dogs operated upon by this method and examined by autopsy or by coronary arteriography, there was proof that the tube remained open in at least 10 cases for at least one month (83 per cent).

b. *"Loop" Method.*—Using the loop technique, 10 dogs were operated upon. Seven of these dogs survived. One dog died on the table from ventricular fibrillation, and 2 dogs succumbed during the first postoperative day from myocardial infarction. In 5 dogs, sacrificed after 4 to 6 weeks, the tube was patent in 4 cases and obstructed in one case.

c. *Anastomosis Between Internal Mammary Artery and Coronary Artery.*—Sixteen dogs were operated upon with anastomosis between the right internal

mammary artery and the right coronary artery. Nylon tubes and polyethylene tubes were used alternately. All dogs survived the operation. Two dogs are still alive, and we intend to keep them alive as long as possible to find out the fate of the anastomosis after long-time survival. One dog died on the eighth postoperative day from pleural empyema; in this animal the polyethylene tube was found to be patent and there were no signs of myocardial infarction. Seven dogs were killed 6 to 8 weeks after the operation. In none of these dogs were there any signs of infarction. In 3 of the dogs, however, there was complete or partial obstruction of the tube, whereas the distal part of the coronary artery was patent. In all 3 cases this happened in relatively small dogs in which a small caliber tube was used.

Six dogs died during the first week after operation, usually on the fourth or fifth postoperative day. In all of these cases, the death was due to hemorrhage caused by slipping of the tube, either from the coronary artery (4 cases) or from the internal mammary artery (2 cases). Polyethylene tubing was used in all of these cases. In none of these dogs were there signs of infarction and, except for post-mortal clotting, the tubes were found to be patent in all but one case, in which thrombosis could not be excluded.

Ventricular fibrillation or cardiac arrhythmia of any kind did not occur during this kind of procedure.

Summing up, in 48 dogs operated upon with insertion of plastic tubes in the coronary artery, there was proof that the tubes remained open after 4 weeks in 16 out of 24 survivors (67 per cent). Since a number of dogs are still living (3 to 18 months after operation), this percentage may be altered as the dogs are re-examined at various intervals.

DISCUSSION

Operative Technique.—The insertion of a small piece of tubing of an inert material in a small coronary artery is a difficult procedure. Once the one end of the tube has been secured in the distal part of the artery, the stiffness of the tube in connection with the movements of the heart makes it a difficult task to insert it in the proximal part of the artery without kinking, or the tube slipping out from the already inserted end. In the beginning, these experiments, in regard to the time used for this part of the operative procedure, took more than 5 minutes as a rule, which is a long time for total occlusion of one of the major coronary arteries and carrying a considerable risk of irreversible ventricular fibrillation. The mean total occlusion time for this procedure in all experiments was 5.3 minutes.

The loop technique was technically much easier to handle. With the freedom of movement provided by the longer loop, the above-mentioned difficulties were partly overcome. This is also demonstrated by the period of occlusion which, with the loop technique, averages 3.7 minutes. Still better and easier is the use of a connection from the internal mammary artery. This could be achieved with less than one minute of occlusion. In the last

two series, no dog died during the operation and there were no alterations in the heart rhythm as judged from direct observation of the heart and a monitoring electrocardiogram.

Two kinds of synthetic material were used in this investigation; nylon and polyethylene tubing. Comparing the two fabrics used by us, the nylon tubing is somewhat more rigid than polyethylene and it is easier to thread into a hole cut in a small vessel. On the other hand, it is more difficult to bend, and we had more trouble inserting it in the proximal hole after the piece of tubing had been secured in the hole distal to the ligature than we had when polyethylene tubing was used. The wall of the nylon tube used by us is thinner than that of the polyethylene tube, permitting a somewhat larger flow with a tube of the same outside diameter. In the long run there were no differences between the two materials since both remained open in a fair number of cases and both apparently provided sufficient blood flow to the myocardium.

In the beginning of these experiments, the tubes were siliconized or saturated with heparin solution. This did not, however, contribute to survival or to a longer period of flow through the tubes, and was later abandoned. This observation is in agreement with that of Donovan[4] who observed that lining with silicone or the use of heparin in polyethylene tubes inserted in the femoral arteries did not increase the average duration of patency. This is also the reason why we did not keep these dogs on anticoagulants during the postoperative period.

Ventricular Fibrillation.—Ventricular fibrillation is a well-known complication after sudden occlusion of a major coronary artery.[2, 14, 15, 19] Since we[8] had good experience with the antifibrillatory properties of procaine amide in another field of cardiac surgery with high fibrillation incidence (namely, open cardiac surgery in hypothermia with venous inflow occlusion), we used this drug in some experiments hoping that in this field also, it should be valuable as a protecting agent. Half of the dogs in the "direct" series received procaine amide as an intravenous infusion during the operation, whereas the other half of the animals were infused with glucose in saline. There was, however, no significant difference in the incidence of fibrillation in these two groups. Thus, it seems that addition of procaine amide to the intravenous fluid drip does not diminish the risk of operating upon the coronary arteries in normothermia.

Fibrillation most often occurred within 30 seconds after the release of the blood flow from the proximal part of the coronary artery. This is a well-known phenomenon.[1, 22] Ventricular fibrillation also was reported shortly after the release of the blood flow to hypothermic hearts after complete inflow occlusion.[21] Sewell, Koth, and Huggins[18] found, after temporary occlusion of the anterior descending coronary artery of the dog, that sudden return of the arterial flow caused ventricular fibrillation in 6 of 31 animals, whereas there were no fatalities if they made the release of the flow intermittently. In the beginning of our experiments, we were not aware of Sewell's and his associates' observations and the release of the flow through the plastic graft was done as

quickly as possible in order to diminish the time of coronary occlusion. Later, we were careful to release the blood flow very slowly and, although the number of experiments do not permit statistical analysis, we have the impression that this procedure was helpful in avoiding ventricular fibrillation. Only one dog fibrillated during an operation using the slow release of coronary blood flow.

Survival of the Dogs.—In a series of experiments reported earlier,[7] a sham operation on the right coronary artery was done, including ligation of the artery, but with no attempt to insert any kind of artificial blood supply to the myocardium distal to the ligature. The mortality with this procedure during the operation and in the immediate postoperative period was 93 per cent. In the three series of dogs, presented in this paper, in which the ligated area in the right coronary artery was bypassed by an artificial graft, the mortality rate was considerably lower; 45 per cent with the "direct" method, 30 per cent with the "loop" method, and 43 per cent using the mammary artery anastomosis. These figures represent the total mortality rate, including technical errors and apparently irrelevant postoperative complications. From these data it is apparent that the plastic tubes, bypassing the ligated part of the coronary artery, contribute to the survival of the animal.

Patency of the Tubes.—Tubes of plastic materials, implanted in small vessels, usually become obliterated by thrombosis very soon. In another series of experiments,[9] we found this also to be true when we inserted tubes of the same size and material as were used in the heart in peripheral systemic arteries. Why, then, do nylon and polyethylene tubes inserted in the coronary artery remain open in so surprisingly high a per cent of the cases? Some explanations may be discussed. The flow in the coronary arteries is faster than in the other arteries of the body. The venous outflow from the coronary system is very efficient due to a network of anastomosing venous channels. A third factor would be that the tubes move with the movements of the heart, causing a constant shaking of the tubes. In these cases, where the tubes were inserted into the distal part of the coronary artery, the squeezing power of the myocardium can hardly be taken into consideration; this, however, would possibly be the case if the tubes had been implanted directly in the myocardium. Sabiston and Fauteux[16, 17] discuss this possibility as the reason why implants of the carotid artery into the right or left myocardium of dogs remained open in a fair number of cases.

Assuming that the chemical composition of the plastic tube itself would have an effect on the clotting of the blood, it would be reasonable to assume that the length and caliber of the tube (namely, the exposed surface of plastic material) would influence the tendency of clotting. Since the elasticity of the tube is less than that of an artery, this would also affect the blood flow, presumably with an increased risk of intravascular clotting parallel to an increase of the length of the tube. The material presented in this paper does not, however, permit any conclusions in this respect.

A last contributory factor could be the anastomosis technique. If an anastomosis between two arteries is accomplished with sutures of any kind, there will almost always be some intimal lesions at the suture line causing a

possible focus for the formation of a thrombus. With the technique used in these dogs, the plastic tube is pushed into a vessel with the intima intact at the place where the end of the tube is secured.

Further experiments with plastic tubes supplying portions of the myocardium are in progress and will be reported separately.

SUMMARY

A technique is described in which nylon or polyethylene tubes were used as artificial grafts, either bridging an occluded part of the right coronary artery or as an anastomosis between the internal mammary artery and the coronary artery distal to a ligature. In 24 dogs, surviving more than 4 weeks (longest period of observation—18 months), the tubes were found to be patent in 16 cases. Some technical points as well as some possible reasons for the patency of the tubes in the coronary artery system are discussed.

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STUDIES OF THE CORONARY CIRCULATION

III. Intramyocardial Implantation of Nylon Tubes After Ligation of a Major Coronary Artery

Knut Haeger, M.D., Malmö, Sweden, and Georg R. Wallgren, M.D.,**Helsingfors, Finland*

IN 1946, Vineberg[1] reported the successful implantation of the left internal mammary artery in the left internal mammary artery in the left myocardium of the dog. Later, it was demonstrated that a collateral circulation developed between the implanted artery and the left descending coronary artery.[2] Some years ago, Vineberg and his associates[3] reported on 4 years of clinical experience with the method; 70 per cent of their patients were reported to be markedly improved after the procedure and were able to return to work.

As was also observed by the originators of the method, significant anastomosis did not develop in all cases, and the lumen of the implanted artery very often was found to be obliterated by endarteritic changes and by thrombi formation.[4, 5, 6] Bakst and his co-workers[6] were unable to find that the implanted artery contributed to the intercoronary anastomotic flow. Many attempts have also been made to modify and improve Vineberg's original method. Julian and his co-workers[7] created fistulas between the internal mammary artery and the mammary vein, and implanted these in the myocardium. They reported that the vast majority of these fistulas closed, but that some remained open a long period of time. Carey and associates,[8] in a two-stage operation, used the internal mammary artery as a bridge between the left atrium and the myocardium, and demonstrated that this procedure afforded a certain degree of protection against ventricular fibrillation or infarction which generally develops following ligation of the descending branch of the left coronary artery. The same group of workers[9] compared the effects of implantation of the subclavian and the internal mammary arteries in the myocardium and found some evidence that the use of the bigger subclavian artery appeared to offer greater protection against infarction and this artery seemed to be less exposed to endarteritic occlusion.

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*Halsted Fellow at the University of Colorado School of Medicine, Denver, Colo., 1957-1958, from the Department of Experimental Surgery, Allmänna Sjukhuset, Malmö, Sweden.

**Foreign Exchange Student of the Institute of International Education, 1957-1958, from Helsingfors, Finland.

In 12 dogs, Sabiston and Fauteux[10] created an anastomosis between the carotid artery and the right myocardium. Three of the dogs died of ventricular fibrillation; in the remaining 9 dogs, however, the implanted artery was found to be patent in 6 cases and thrombosed in 3. When the left carotid artery was implanted in the left myocardium, the vessel was found to be grossly patent in 28 out of 32 animals. The time of observation varied between 22 and 246 days.[11] Smith and co-workers[12] connected the aorta with the left myocardium by means of a vessel graft or a nylon tube, and demonstrated the graft to be open in the dog after one year. In 2 human patients they used a venous graft and a nylon tube, respectively, and reported excellent postoperative results in both cases. Finally, Massimo and Boffi[13] created a canal between the left ventricular cavity and the left myocardium by means of a nylon T-tube (4.5 mm. in diameter) and reported good results in the experimental animals.

It seems that one of the major problems using the Vineberg approach, or its modifications, is the impending risk of intimal proliferation and subsequent thrombosis of the supplying artery. We[14] found polyethylene or nylon tubes remain open in a fair percentage of dogs when the tubes are inserted in the coronary artery. Therefore, we decided to use similar tubes as a bridge between the internal mammary artery and the ischemic myocardium.

METHODS

Mongrel dogs weighing between 7 and 20 Kg. were anesthetized with 30 to 40 mg. per Kg. Nembutal intravenously. After intubation, the respiration was artificially maintained with 100 per cent oxygen. After thoracotomy in the lateral position, the internal mammary artery was dissected to 10 to 15 mm. from its origin, and was divided so a 30 to 40 mm. free proximal stump was obtained. Then the artery was transposed to the mediastinal side of the pleural cavity by means of some 5-0 silk stitches. A nylon tube* (outer diameter, 1.57 to 2.80 mm.) was inserted into the arterial stump and secured by two or three 3-0 silk ligatures. The other end of the tube, which previously had been perforated with a hot needle in several places, was attached to a silk ligature. Using a slightly curved or straight needle, this end was buried subendocardially in the myocardium parallel to one of the major coronary arteries (Fig. 1). In some cases, the distal end of the tube could simply be pushed into place through a small epicardial incision. If any bleeding occurred at the ends of the buried part of the tube, the hole was closed with atraumatic 5-0 silk, sometimes tied over a small piece of Gelfoam.

Finally, the selected coronary artery was ligated and the blood flow from the mammary artery via the tube was released. In some instances, a small hematoma developed around the buried tube. In the last dogs operated upon, the myocardial end of the tube was closed so the blood could only leave it through the small needle-stick holes. The bridging part of the tube was secured to convenient tissues such as the auricular wall, the pericardium, or

*Thermoglas, Inc., Gothenburg, Sweden.

the mediastinal pleura. Usually the pericardium was left open. In a few cases, however, a small portion of it at the base of the heart had to be closed with a few stitches to keep the tube in place. The thoracic cavity was closed, suction drainage was begun, and the dog was left with artificial respiration of 100 per cent oxygen or air, one to 2 hours postoperatively.

On the right side the coronary artery was ligated just proximal to the main bifurcation; on the left side either the descending branch or the circumflex branch was ligated within 10 mm. of its origin. Care was taken that the septal artery escaped ligation. In 7 dogs, the operation was performed on both sides. The two operations were separated by a 6- to 10-week interval.

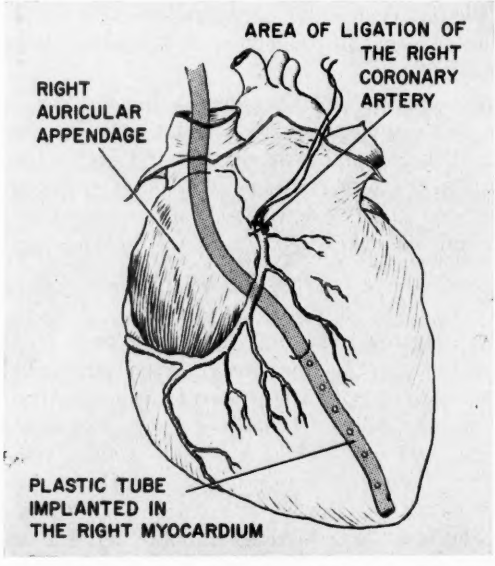
AREA OF LIGATION OF THE RIGHT CORONARY ARTERY
RIGHT AURICULAR APPENDAGE
PLASTIC TUBE IMPLANTED IN THE RIGHT MYOCARDIUM

Fig. 1.—Implantation of a plastic tube in the myocardium.

In 9 dogs the tube was implanted on the left side near the descending coronary artery, after which this artery was ligated. After some days the dog was anesthetized and the chest re-opened under sterile conditions. The tube was inspected, the presence or absence of flow through it noted, and then the tube was left clamped. The chest was closed and the fate of the dog observed.

With the purpose of finding out whether the nylon tubes would behave in a similar way when inserted in the arteries of the general circulatory system as in the coronary system, the following series of experiments were done. In 8 dogs, nylon tubes of the same size and type as used in the myocardium were embedded into various organs, or used as a bridge between two parts of a peripheral artery. The tube was inserted in the artery as described above and was then embedded in the organ in the same manner as in the heart and

secured by one or two silk stitches. When buried in skeletal muscles, a growing hematoma could be observed at the release of the blood flow, and sometimes catgut ligatures had to be made to prevent bleeding. In those cases where the tube was inserted in the distal part of an artery, the same technique was used as in the proximal part.

RESULTS

The unilateral procedure was carried out in 12 dogs, 6 on the left side and 6 on the right side. All dogs survived the operation. During the insertion of the tube, cardiac arrhythmia sometimes occurred, especially sinus tachycardia and ventricular extrasystoles. There was, however, no ventricular fibrillation.

Fig. 2.—Specimen from a dog's heart 2 weeks after the implantation of a nylon tube in the myocardium. The tube is removed from its bed. The endothelial-covered canal which developed around the tube is demonstrated.

The fate of the experimental animals is evident from Table I. One dog died 3 days after the operation; unfortunately, no autopsy was done on this animal. Another dog died from distemper on the twenty-fifth postoperative day. The remaining 10 dogs all survived in excellent condition. They were later sacrificed after different periods of observation between 4 weeks and 7 months. At autopsy, there were some indications of old myocardial scars in some of the dogs; in most cases, however, the myocardium appeared completely healthy. Nor, at histologic examination in some of the cases, could any signs of infarction be seen in these animals.

In 5 dogs, the tubes were found to be patent and in 5 cases they were obstructed by thrombotic material. In one case, the patency was considered as doubtful. There were no dogs in this series, sacrificed later than the sixth

TABLE I. UNILATERAL OPERATION

EXPERIMENT NO.	FATE OF THE DOG	TUBE	AUTOPSY FINDINGS
1	Died 3 days postop.	?	No autopsy
2	Died 25 days postop.	Patent	Distemper; no signs of infarction
3	Sacrificed 4 weeks	Patent	No signs of infarction
4	Sacrificed 4 weeks	Patent	No signs of infarction
5	Sacrificed 6 weeks	Patent	No signs of infarction
6	Sacrificed 6 weeks	Patent	No signs of infarction
7	Sacrificed 6 weeks	Obstructed	No signs of infarction
8	Sacrificed 8 weeks	Obstructed	Myocardial scars
9	Sacrificed 5 months	Obstructed	No signs of infarction
10	Sacrificed 6 months	Obstructed	No signs of infarction
11	Sacrificed 6 months	Obstructed	Myocardial scars
12	Sacrificed 8 months	Obstructed	No signs of infarction

week, that had a patent tube. On the other hand, the tubes usually were open when the dogs were killed within this period of time. The tubes were found embedded in the myocardium and surrounded by endothelial tissue (Fig. 2). In some instances, there were small openings in this endothelial cover corresponding to one of the holes in the tube.

Seven dogs were operated upon on both sides. One of these dogs died 7 days after the second operation. At autopsy, the last implanted tube was found to be partially obstructed by a thrombus; the lumen was decreased by approximately 75 per cent. There were also signs of infarction in the area supplied by the descending branch of the left coronary artery which was ligated at the second operation. On the right side, the tube was found to be completely obstructed, but there were no signs of old or recent myocardial damage. The interval between the two operations was, in this case, 9 weeks. Four of the surviving dogs were killed 4 to 6 months after the second operation and, in all cases, the tubes were found to be completely obstructed by thrombi.

Nine dogs were operated upon with tube implantation and simultaneous ligation of the left descending coronary artery. Two to 7 days later the chest was re-opened and the tube examined. The results are given in Table II. It is seen that the mortality is high when the tubes were clamped within a few days of the original operation, and the tubes usually were patent at this time.

TABLE II. FATE OF THE DOGS AFTER EARLY CLAMPING OF THE INTRAMYOCARDIAL TUBE

EXPERIMENT NO.	CLAMPING (DAYS AFTER ORIGINAL OPERATION)	TUBE PATENT (+) OR OBSTRUCTED (−)	FATE OF THE DOG
1	2	+	Died 2 days later
2	2	+	Died 3 days later
3	3	+	Died 2 days later
4	3	+	Died within 24 hours
5	5	+	Died within 24 hours
6	5	+	Died within 3 days
7	7	−	Survived
8	7	+	Survived
9	7	+	Died from vent. fibrill. on table

The results of the experiments on the peripheral arteries are shown in Table III. As is seen in the table, only two tubes remained open after an observation time of 5 and 14 days, respectively. All other tubes were completely obstructed by thrombosis. Signs of hematomas in more or less degree of fibrous organization were found in the kidney, spleen, and skeletal muscles. A comparison of Tables I and III reveals that if the tubes were implanted in the myocardium, they generally remained open for a much longer time than if similar tubes were implanted somewhere in the systemic circulation.

TABLE III. THE FATE OF NYLON TUBES IMPLANTED IN VARIOUS SYSTEMIC ARTERIES

EXPERIMENT NO.	NYLON TUBE		REMOVAL DAYS	FATE OF TUBE
	FROM	TO		
20	Femoral artery	Femoral artery	10	Obstructed
21	Femoral artery	Femoral artery	20	Obstructed
22	Femoral artery	Femoral artery	23	Obstructed
23	Carotid artery	Carotid artery	20	Obstructed
24	Femoral artery	M. sartorius	5	Obstructed
25	Femoral artery	M. sartorius	5	Patent
26	Femoral artery	M. sartorius	10	Obstructed
27	Femoral artery	M. sartorius	12	Obstructed
28	Femoral artery	M. sartorius	12	Obstructed
29	Femoral artery	M. sartorius	20	Obstructed
30	Femoral artery	M. sartorius	23	Obstructed
31	Carotid artery	M. sternocleidomast	20	Obstructed
32	Splenic artery	Spleen	10	Obstructed
33	Splenic artery	Spleen	12	Obstructed
34	Splenic artery	Spleen	12	Obstructed
35	Splenic artery	Spleen	14	Patent
36	Splenic artery	Spleen	23	Obstructed
37	Splenic artery	Liver	3	Obstructed
38	Renal artery	Kidney	12	Obstructed
39	Int. mamm. artery	M. intercostalis	2	Obstructed

COMMENTS

Technical Considerations.—In earlier experiments in this laboratory,[14] we used alternatively nylon or polyethylene tubes as a connection between the internal mammary artery and the coronary arteries. It was then observed that the more rigid-walled nylon tubes were more suitable for this kind of procedure and, in the present series, nylon tubes were used exclusively. In the latter part of the investigation we abandoned the use of thread and needle and simply pushed the tube into the myocardium. This could be done easily if the end of the tube was closed and formed to a sharp-pointed probe. This, also, was found to be favorable since the hematoma developing around the embedded part of the tube was much less pronounced with this method.

In this series, no ventricular fibrillation occurred. In another series of dogs, reported earlier,[14] the incidence of ventricular fibrillation was 5 out of 27 cases. In the present series, the blood supply to the myocardium was not occluded during the actual manipulations with the heart, and the myocardium was supplied from the internal mammary artery at the time when the coronary artery supplying this area was ligated. Whether the incidence of ventricular fibrillation would arise, if this operation should be undertaken

on individuals with previous impairment of the coronary flow, remains to be investigated. Preliminary results in dogs operated upon with this technique after artificially induced coronary thrombosis and subsequent myocardial infarction do not, however, indicate a significant increase in the incidence of ventricular fibrillation.[15]

Protection Against Death Following Coronary Artery Ligation.—The experimental evaluation of a method for supplying arterial blood to the heart is very difficult since the results of the irritation caused by the pericardiotomy alone seem to offer a certain degree of protection.[16] As pointed out by Garamella and associates[17] and, indirectly, by Milch and his associates[18] control experiments from other laboratories cannot be relied upon due to the numerous variables of acute ligation of a major coronary artery. This is also very clear from the varying results of acute coronary ligation as they have been reported by numerous investigators. For an adequate comparison, the animals of the control series should be treated exactly as those of the experimental series, and the ligation of the coronary artery in the former should be done with the same operative trauma as in the procedure under investigation. In other words, the ligation of the coronary artery in the control series should be made as a sham-operation simulating the operative technique of the procedure under investigation.

Such sham operations on the right coronary artery were made in this laboratory with an immediate postoperative death of 93 per cent. After high ligation of the left descending coronary artery (the septal branch not included), the mortality in 7 dogs was 100 per cent. In the latter series, the septal branch was not included; the observance of this detail is of importance.[19] The mortality following unilateral intramyocardial implantation of nylon tubes and simultaneous corresponding ligation of a major coronary artery was 2 out of 12 dogs in this series. Consequently, it appears the implantation of the nylon tube added to the protection of the heart.

The Patency of the Tubes.—Apparently nylon tubes implanted into the myocardium remain open for some time but later, probably after about 6 weeks, become occluded by thrombosis. On the other hand, when similar tubes were used in an identical manner in various parts of the systemic circulation, they usually became obstructed very early. In some instances, there was proof of obstruction at the second to the fifth day after operation.

Six weeks is an astonishingly long time. Nevertheless, it is considerably shorter than when tubes of the same caliber were inserted directly in the coronary vessels. In earlier experiments, in which this technique was used, we have seen such tubes occasionally remain patent more than one year.[14, 20] At the present time, we are satisfied that the intramyocardially implanted tubes remain open long enough to supply the myocardium with oxygenated blood during the critical phase after ligation of a coronary artery. This critical period is the time during which the normally resting intra- and extracoronary anastomoses need to develop as functional units, a period which in the dog is stated to be between 4 and 12 days after the ligation.[21]

There seems to be some fundamental difference between the tendency to clot in a tube of inert material inserted into a peripheral artery and a coronary artery, respectively. It is to be remembered, though, that morphologically, as well as physiologically, there is a marked dissimilarity between the vascular supply to the heart and that of any other organ or part of the body.

First, the blood vessels in the myocardium are embedded in a tissue, the syncytial structure of which is not similar to any elsewhere in the body. Furthermore, there is no organ that is so well supplied with afferent as well as efferent blood vessels as the myocardium. The amount of capillaries in the adult human myocardium is calculated to be between 3,000 and 4,000 per square millimeter, as compared with less than 2,000 capillaries per square millimeter in the skeletal muscle. In the normal adult heart every single fiber is supplied by its own capillary, which also is an unique arrangement.[22]

There is now a general agreement that the coronary arteries are end-arteries in the physiologic sense; i.e., one artery branches within the region where it runs and supplies this and no other area. From the anatomic point of view, however, they are not end-arteries since there is a richly developed system of interarterial anastomoses at different levels throughout the length of the artery. It is believed that during normal conditions at least most of these communications are closed. After injection of fluids of high viscosity, too thick to penetrate the capillaries, these anastomoses were found to be of considerable size, but it was a rare finding to have one coronary artery filled with the material injected into another.[23, 24] Given enough time, the interarterial anastomoses open up after some kind of stimulation, as for instance, if a pressure gradient develops between two arteries,[25] or if the biochemical milieu in the heart in some way is altered, as for instance, by tissue hypoxia.[26] This is an important difference between the coronary system and, for example, the arteries of an extremity. Another dissimilarity that may be important as regards the clotting mechanisms is the spontaneous rhythmical movements of the coronary arteries as reported by Rothlin[27] and Häusler and Filippi.[28]

The smooth muscles in the walls of the coronary arteries are arranged somewhat differently from those in a peripheral artery. In the proximal part of a coronary artery near the aortic ostium and, also, in the distal parts of the artery near the apex of the heart, the smooth muscle fibers are arranged as a spiral. The purpose of this arrangement is not clearly understood; probably it serves as some kind of protective mechanism to ensure coronary flow throughout the cardiac cycle. A similar mechanism has been reported in the cardiac veins.[29] The walls of these veins contain more smooth muscle, comparatively, than other veins; especially, the longitudinal layer of muscles in the cardiac veins are very well developed. This permits the veins to exert an active resistance to the pressure of the surrounding myocardial muscle and, thus, the venous outflow from the myocardium is secured even under myocardial systole. The topographical arrangement of the cardiac veins in several different and independent systems also provides excellent facilities for

drainage of blood from the myocardium. In our experiments, little or no hematoma developed around the perforated end of the tube after its implantation into the myocardial muscle, whereas large hematoma immediately developed around the same kind of tube inserted in a skeletal muscle or in a parenchymatous organ. The very effective venous drainage system probably is responsible for this difference. It is well known that stasis is a predisposing factor for intravascular clotting, and it might be that these effective drainage facilities prevent stasis around the tube and indirectly permits a steady flow through the tube. In the papers by Sabiston and Fauteux,[10, 11] there are some observations which support this hypothesis. They implanted the carotid artery in the right ventricular wall and observed a flow of between 1.6 and 3.2 c.c. per minute in the graft in some of their animals. If, however, the conditions of draining were improved by partial communication of the graft with the cavity of the heart, the amount of flow through the implanted artery increased tenfold or more. This may be taken as evidence of the significance of good drainage to the flow in the afferent part of the system. In our series we did not deliberately attempt to drain the tubes partially to the ventricular cavities. It is possible it would be wise to do so in the future.

The vasomotor innervation of the coronary arteries "is unsurpassed by any other artery in the body."[30] Both divisions of the autonomic nervous system are represented. It is now held that, contrary, to the systemic arteries, the parasympathetic nerves carry the vasoconstrictor fibers and the sympathetic nerves the vasodilator fibers. According to Poiseuille's law, even very little diminution of the cross surface of an artery influences the flow considerably. This has also been experimentally demonstrated by Mann and associates.[31] Since there is a difference in the vasoconstriction innervation of the coronary system and the peripheral system, it might be that vasoconstriction occurs to a lesser degree in the former arteries and, thus, the chances of impairment of blood flow are less pronounced.

In the dog, the mean heart weight is about 0.75 to 1.0 per cent of the total body weight.[32] This comparatively small fraction of the total weight of the animal is, however, supplied by no less than 4 to 5 per cent of the total cardiac output; in emergencies it can rise as high as 14 per cent.[33] This means that the flow in the coronary arteries, even under resting conditions, is very high, and definitely higher than in the systemic arteries. Assuming the total coronary inflow in the normal resting dog averages about 70 c.c. per 100 gram left heart per minute,[33] the flow through the coronary artery will be just a little more than 1 c.c. per second. In a coronary artery with an internal diameter of 2 mm. this means that the velocity of the blood stream will be about 30 cm. per second. The velocity of the blood stream through the aorta has been theoretically calculated to be about 22 cm. per second,[34] and, experimentally, values about 18 cm. per second have been reported.[35] When the aorta branches in smaller arteries, the combined cross

section areas of these increase and the velocity decreases. In the peripheral extremity arteries, velocity figures of about 10 to 20 cm. per second are reported.[36]

Thus, the velocity of the blood stream through the coronary arteries is at least two times faster than that of peripheral arteries of corresponding size. Also, this fact may add to the lesser tendency of intravascular blood clotting in tubes connected with the coronary system. Of course, this factor is irrelevant when the nylon tubes are implanted directly in the myocardium, but certainly it may have some bearing when pieces of tubes are used as a bypass and inserted as a bridge between two severed parts of a coronary artery.

Also, in other respects, the dynamics of blood flow are different in the coronary arteries and in the peripheral arterial system. A comparison of the interrelations of pressure, vascular volume, and flow in the coronary artery and, for example, in the femoral artery, reveals some interesting points. In the peripheral artery there is a rapid increase in flow at the onset of systole. This increase reaches its peak shortly before the arterial pressure starts to fall, and then begins to diminish rapidly. As the vascular volume is increased, there is a retardation of the flow and for a moment there is a short period when the flow not only is decreased, but even reversed. Wright and Phelps[37] showed this was true in the arteries of the extremities and in the common carotid arteries, whereas there was no evidence of reversal of flow in the renal, hepatic, and superior mesenteric arteries.

In the coronary arteries, on the other hand, the pattern of the flow curve is different. As was demonstrated by Gregg and Green,[38] in the dog there is a very short period of backflow also in the coronary arteries at the onset of the phase of isometric contraction in the myocardial muscle. This period, however, is considerably shorter than the backflow phase of the peripheral arteries. In the coronary arteries, it lasts about $\frac{1}{20}$ of the total cardiac cycle, whereas it is little more than two times that length in the peripheral system.[37, 38, 39] The amount of blood that is rejected during the backflow phase is negligible in the coronary arteries. It amounts to about 0.006 ml. per heartbeat in the dog as compared with a total flow of about 0.2 ml. per heartbeat during the whole cycle. As in the peripheral arteries, there is also a diminution of flow with falling aortic pressure, but in the coronary arteries the flow never reaches the zero line in this phase and, during diastole it quickly rises again after the closure of the aortic cusps.

It is difficult to say whether these hemodynamic differences may play a role for the tendency of clotting and thus explain why tubes inserted in the coronary system remain open for a longer time than tubes in the systemic arteries. Although it is well established that stasis is an important factor in the pathogenesis of thrombosis, we have no evidence that a small relative difference of, for instance, the duration of the backflow phase in two arterial systems may influence the intravascular clotting propensity. For the moment we only want to stress that important dissimilarities do exist between

the coronary and the systemic circulation, and that one or more of these differences may account for the varying results obtained after insertion of nylon tubes in the coronary system and the peripheral system, respectively.

In the present studies we have used a nonsuture technique at the insertion of the tubes. In an earlier paper from this laboratory,[14] it was discussed whether this might have added to the sustained patency of the tubes. It was demonstrated by Blakemore and Lord[40] and by Egdahl and Hume[41] that the nonsuture method may be effectively used in small arteries. In the present series, however, in which the nonsuture technique was used in both peripheral vessels and in arteries inserted into various parenchymatous organs on one hand, and in tubes inserted into the myocardium or into the coronary arteries themselves on the other, there was a marked difference in the frequency of thrombosis. This probably means that the nonsuture technique per se is not responsible for the favorable results observed when the tubes were inserted in the heart.

An alternative explanation could be offered if the clotting mechanism were inhibited by some local factor in the myocardium or modified by some alterations caused by changes in the heart metabolism after infarction. Some pilot experiments to clarify this problem were undertaken in this laboratory. As yet, however, no certain evidence of such a mechanism has been established. Some observations reported in the literature are, however, of interest. Tietze and Schulz[42] reported an increased fibrinolytic activity in plasma following myocardial infarction in man; Tagnon and co-workers[43] observed fibrinolysis during hemorrhagic shock, and Kwaan and McFadzean[44] demonstrated the appearance of a fibrinolytic substance in the blood running through an extremity temporarily deprived of its arterial supply. These observations support the concept of a decreased tendency of intravascular clotting in an ischemic area. On the other hand, Hume[45] observed a depression of the fibrinolytic activity in patients with myocardial infarction during the first 8 days after the onset of the disease. Thus, the reports in this field are controversial, and for the moment nothing can be said of the role of the biochemical factors in the clotting mechanism as applied to the patency of artificial tubes inserted in the myocardium.

SUMMARY

Nylon tubes were inserted into the internal mammary artery in the dog and the other perforated end of the tube was embedded in the myocardium close to one of the major coronary arteries. The pertinent artery was subsequently ligated and the results of this operation were compared to control experiments without implantation of tubes.

The mortality after acute ligation of the right coronary artery in the dog was, under the conditions of these experiments, 93 per cent, and ligation of the left descending coronary artery, 100 per cent. After implantation of tubes, 10 dogs out of 12 survived. The tubes were usually found to be patent if the

dog was sacrificed within 6 weeks; otherwise, the tubes were found to be obstructed by thrombosis. Six dogs out of 7 survived bilateral coronary ligation after tube implantation in two stages.

When the tubes were inserted in peripheral arteries and either embedded in parenchymatous organs or skeletal muscle, or were inserted in the peripheral stump of the same artery, there was early thrombosis in 18 out of 20 experiments.

When a tube was inserted in the myocardium and the pertinent coronary artery ligated and the tube later was clamped, the dog did not survive if the clamping was done within 5 days after the original operation.

It is felt the implantation of nylon tubes supplying the ischemic myocardium with arterial blood from the internal mammary artery adds to the protection of the heart from death of myocardial infarction. The possible reasons for the prolonged patency of the tubes implanted in the heart are discussed.

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STUDIES OF THE CORONARY CIRCULATION

IV. Surgical Treatment of Acute Experimental Myocardial Infarction in the Dog

Knut Haeger, M.D., Malmö, Sweden, and Georg R. Wallgren, M.D.,** Helsingfors, Finland*

CONTRARY to the case of acute occlusion of a peripheral artery, the acute occlusion of a coronary artery generally has been considered a subject of non-surgical treatment. However, as early as 1947, Gordon Murray[1] predicted that "the day may come when the best plan of dealing with a coronary thrombosis would be an emergency operation." He supported this view with experiments on dogs, in which the ballooning area occurring after myocardial infarction was excised. He noted this procedure of reducing the paradoxical systole of the infarcted area not only increased the rate of survival but also markedly improved the cardiac output and increased the blood pressure. Cardiostatorrhaphy, as described by Allen,[2] also attempts to prevent or diminish the area of ballooning. This author stated that the heart became more efficient after this procedure of stabilization and compression of the ischemic area.

Temesvári[3] created myocardial infarction by acute ligation of the right coronary artery in dogs. Twelve to 48 hours later he excised the ischemic area and covered the defect with a pedicled flap of the diaphragm or the pectoral muscle. Detailed information of the rate of survival in these dogs as compared with untreated animals is not given in this paper. It is, however, stated that some of the dogs survived the operation by 8 to 10 months. At autopsy, the flaps were found to be subjected to fibrous degeneration and, in some cases, even to the formation of cartilaginous tissue. Also, Forcheri and Castellani[4] excised the ischemic part of the myocardium after ligature of the middle third and the left anterior coronary artery. Although these authors observed the cicatrization was more certain and stronger following resection of the infarcted area, they recommend the procedure only in selected cases, due to the high operative mortality.

As far as we know, the above-mentioned procedures are the only attempts of surgical intervention in acute myocardial infarction in experimental animals.

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*Halsted Fellow at the University of Colorado School of Medicine, Denver, Colo., from the Department of Experimental Surgery, Allmänna Sjukhuset, Malmö, Sweden.
**Foreign Exchange Student of the Institute of International Education from Helsingfors, Finland.

Until recently, it has been difficult to produce slow coronary occlusion resembling the conditions in man. In 1956, however, Gage, Olson, and Chardack[5] reported on a simple and ingenious method to create coronary thrombosis and subsequent myocardial infarction in the dog. The insertion of a magnesium-aluminum alloy needle in one of the major coronary arteries makes it possible, in the dog, to produce a slowly developing coronary thrombosis, causing clinical and electrocardiographic evidence of myocardial ischemia.

In earlier experiments in this laboratory,[6] we found that dogs survived acute ligation of one of the major coronary arteries if a nylon tube was inserted in the internal mammary artery and embedded in the myocardium. In those experiments, the tube was implanted in healthy myocardium and the occlusion of the pertinent coronary artery was not made until the extracardial arterial blood supply had been established through the tube. Since we found these tubes mostly remained patent, at least for some weeks, it occurred to us a modification of this procedure might be useful in the treatment of acute myocardial infarction. It is the purpose of this paper to report the results of intramyocardial implantation of a nylon tube at a time when myocardial ischemia was present.

METHODS

For the experiments, adult healthy mongrel dogs of both sexes, weighing 10 to 25 Kg., were used. The dogs were anesthetized with intravenous Nembutal (30 to 40 mg. per kilogram of body weight) and intubated. Artificially controlled respiration using 100 per cent oxygen was maintained throughout the operation and continued for some hours postoperatively.

The right or left side of the heart was alternatively exposed by a thoracotomy in the fourth or fifth interspace in the lateral position. The pericardium was opened and the chosen coronary artery carefully dissected. An 18 to 23 mm. piece of a magnesium-aluminum alloy wire* was inserted into the lumen of the artery. The technique is described in detail by Gage and his co-workers.[5] In the right coronary artery, the wire was placed just proximal to the main bifurcation; in the left descending artery, as near the main bifurcation as possible without interference with the septal artery; and, in the left circumflex artery, just distal to the main bifurcation of the left common coronary artery. Minor aberrations from these sites could not be avoided in some animals. Thus, in one case the septal artery was blocked, which resulted in infarction of the interventricular septum and subsequent damage to the conductive system.

After insertion of the wire, the pericardium was closed, the lung expanded, and the chest was closed with suction drainage. Electrocardiograms were recorded before and after the operation, and repeatedly during the postoperative course. The electrocardiographic observations will be subjected to a detailed analysis and published separately.[7]

*Magnesium (98%) and aluminum (2%). We are indebted to the Denver Branch of the Aluminum Company of America for a generous supply of this alloy.

Sixteen dogs were treated only with the described procedure and were kept as controls. Postmortem examination was made in all cases and evidence of coronary thrombosis and myocardial infarction was noted.

Another 15 dogs were observed clinically and with repeated electrocardiograms on the days following the insertion of the wire. When electrocardiographic signs of myocardial ischemia were present, and/or the condition of the dog became alarming. It was reoperated upon. The previous skin incision was opened and the thorax was entered through the same or an adjacent interspace. A nylon tube* (external diameter 2.4 to 2.8 mm.) was inserted into the internal mammary artery as described in an earlier paper.[6] A purse-string 3-0 silk suture was placed in the myocardium close to the ischemic area and a 1 to 2 mm. incision was made in the epicardium. It was noted that if the suture was placed inside the bluish, sometimes bulging, ischemic area, it very easily cut through the muscle fibers and had to be replaced in an intact area.

The distal end of the tube that was perforated was filled with blood from the mammary artery and pushed through the epicardial incision. The purse-string suture was tightened around it and tied over a small piece of Gelfoam. An attempt was made to place the intramyocardial part of the perforated tube at the borderline between the healthy and the ischemic parts of the myocardium. After release of the blood flow through the tube, there usually was no, or very little, bleeding backward from the epicardial incision. The tube was secured to convenient tissues by some silk stitches. Special care was taken that the tube did not create a possibility for herniation of the lung.

In 6 dogs the same operation was undertaken on the same indications as above, but in these cases the nylon tube was closed and thus, a sham operation was performed without any blood entering the myocardium from the internal mammary artery.

Since it is known that adhesions may form between the pericardium and the epicardium,[8] rendering additional myocardial blood supply, the pericardial incision was closed only at the base of the heart to cover the tube. The chest was closed with drainage. The dog was kept on artificial respiration with 100 per cent oxygen one to 2 hours postoperatively, and 500,000 I.U. of penicillin was given intramuscularly. Electrocardiograms were recorded before the operation and during the postoperative course.

RESULTS

The 16 dogs which were only subjected to Mg-Al wire implantation died within 15 days of the operation (Table I). However, 4 dogs fibrillated during or immediately after the operative procedure. These deaths must be a sequel of the manipulations of the coronary artery or caused by mechanical occlusion by the wire per se.

*Thermoglas, Inc., Gothenburg, Sweden.

At postmortem examination of the remaining dogs, myocardial infarction was observed in all cases. In 4 dogs, surviving 4 to 15 days after the wire implantation, the wire was dissolved and a thrombus was found at the site of the implantation (Fig. 1). In some other cases there was slight erosion on the surface of the wire, and there were signs of beginning thrombus formation (fibrin deposits, etc.).

Fig. 1.—Thrombus attached to the wall (*at arrow*) of the right coronary artery 7 days after the insertion of a magnesium-aluminum alloy wire.

TABLE I. CONTROL EXPERIMENTS

EXPERIMENT NO.	SITE OF Mg-Al WIRE IMPLANTATION	DEATH (TIME AFTER IMPLANTATION)	NOTES
1	Right coronary artery	1 hour	Ventricular fibrillation
2	Right coronary artery	4 hours	Severe myocardial ischemia
3	Right coronary artery	4 days	Severe myocardial infarction
4	Right coronary artery	7 days	Artery occluded by thrombus, myocardial infarction (Fig. 1)
5	Right coronary artery	8 days	Artery occluded by thrombus, myocardial infarction (Fig. 1)
6	Right coronary artery	15 days	Artery occluded by thrombus, myocardial infarction (Fig. 1)
7	Left descending artery	Immediately	Ventricular fibrillation
8	Left descending artery	3 hours	Ventricular fibrillation
9	Left descending artery	1 day	Myocardial infarction
10	Left descending artery	2 days	Myocardial infarction
11	Left descending artery	4 days	Artery occluded by thrombus, myocardial infarction
12	Left descending artery	6 days	Septal artery blocked, septal infarction, infarction of the myocardial wall
13	Left circumflex artery	Immediately	Ventricular fibrillation
14	Left circumflex artery	2 days	Myocardial infarction
15	Left circumflex artery	2 days	Myocardial infarction
16	Left circumflex artery	4 days	Myocardial infarction

In the series of dogs which were operated upon with the tube implantation, the wire was inserted at the same stage as the tube in 2 dogs (Table II). The

TABLE II. DOGS WITH EXPERIMENTALLY INDUCED CORONARY THROMBOSIS AND MYOCARDIAL INFARCTION, SUBSEQUENT IMPLANTATION OF TUBE

EXPERIMENT NO.	SITE OF Mg-Al WIRE IMPLANTATION	TUBE INSERTED (DAYS AFTER FIRST OPERATION	FATE OF DOG	NOTES
17	Right coronary artery	Simultaneously	Died 2 days later	Pleural empyema, tube patent
18	Right coronary artery	3	Survived	
19	Right coronary artery	3	Survived	
20	Right coronary artery	4	Survived	
21	Left descending artery	Simultaneously	Died 1 day post-op.	Pulmonary atelectasis, tube patent
22	Left descending artery	2	Survived	
23	Left descending artery	2	Survived	
24	Left descending artery	3	Survived	
25	Left descending artery	3	Died 15 days later	Abortion; tube patent; coronary art. occluded; old infarction
26	Left descending artery	4	Survived	
27	Left descending artery	4	Survived	
28	Left descending artery	4	Vent. fibrill. immediately post-op.	
29	Left descending artery	7	Survived	
30	Left circumflex artery	2	Survived	
31	Left circumflex artery	2	Survived	

other dogs were operated upon 2 to 7 days after the wire implantation. In these dogs, as a rule, we found at the second operation definite microscopic evidence of myocardial infarction, which was in most cases substantiated by electrocardiograms and the clinical state of the animal. There was bluishness over the area of distribution of the pertinent artery, and at probing there was lack of myocardial tonus. The vessels of the bluish area were straightened out and flattened. It was felt there was a difference in contractile strength between this area and the surrounding healthy myocardium. Sometimes, also, definite bulging of the ischemic area was observed and, in a few cases, there was paradoxical systole. The borderline between the pathologic and the healthy-looking area usually was rather sharp.

After implantation of the nylon tube in the myocardium, no immediate changes in the color or general appearance of the ischemic area could be seen. Eleven out of 15 dogs operated upon with tube implantation survived, the time of observation being at least 4 months. One dog died from ventricular fibrillation immediately after the closure of the chest. Two dogs died from pleuropulmonary complications; in these dogs the tubes were found to be patent. Another dog died 15 days after the second operation. Also, in this dog the tube was found to be patent, and the myocardium was in the healing stage of infarction.

A blind tube was implanted in the myocardium in 6 dogs (Table III). All of these dogs died shortly after the second operation. The longest survival was 6 days after the sham tube implantation and 10 days after the wire implantation.

TABLE III. SHAM OPERATION—BLIND NYLON TUBE IMPLANTED IN DOGS WITH SIGNS OF MYOCARDIAL INFARCTION

EXPERIMENT NO.	SITE OF Mg-Al WIRE IMPLANTATION	BLIND TUBE INSERTED (DAYS AFTER FIRST OPERATION)	FATE OF THE DOG	NOTES
32	Right coronary artery	4	Died 6 days after 2nd operation	Myocardial infarction
33	Right coronary artery	4	Died 1 day after 2nd operation	Myocardial infarction
34	Left descending artery	2	Died 3 hours after 2nd operation	Myocardial infarction
35	Left descending artery	3	Died 1 day after 2nd operation	Ventricular fibrillation
36	Left descending artery	3	Died 3 days after 2nd operation	Severe myocardial infarction
37	Left descending artery	3	Died 3 days after 2nd operation	Severe myocardial infarction

Summing up, in a control series with induced coronary artery occlusion and myocardial infarction, the mortality was 100 per cent. In a similar series, treated with intramyocardial implantation of a nylon tube carrying blood from the internal mammary artery, the rate of survival was 11 out of 15 animals (73 per cent). When a sham procedure was undertaken with a closed nylon tube in 6 animals, all died within 6 days of the sham operation.

DISCUSSION

If a magnesium-aluminum wire is inserted into a major coronary artery, one of three things may happen. The dog may die from ventricular fibrillation in connection with the operative procedure (it is well known that manipulations and even temporary occlusion of a coronary artery often result in this complication). Second, the wire itself could obstruct the lumen, causing myocardial ischemia rather quickly after the insertion. Third, a thrombus could develop around a skeleton of metal meshwork, and this thrombus could progressively obstruct the lumen. In the control series, probably all three alternatives are represented. For a comparison with the experimental series, only the dogs with a slowly developing thrombosis are of value. In the control series, 11 such dogs are included, all of which died between the second and fifteenth day of the implantation of the wire. Judging from the findings at

the second operation in the experimental series, we believe it possible that these dogs also would have succumbed from their infarction within the first 2 weeks. Since these animals survived, we believe the second operation prevented their death by the implantation of a tube.

In the experimental series in which a blind nylon tube was implanted, all dogs died within the same time limits as did the control dogs. This must be taken as evidence that the implanted open tubes remained patent, at least for some time, and that they effectively supplied arterial blood to the ischemic parts of the heart. In another series, we investigated the patency of the tubes in the living animal at a short interval after its implantation in the myocardium,[6] and found that most of the tubes were patent within the first week. Furthermore, if the patent tubes were clamped, the animal died from myocardial infarction, another piece of evidence that the implanted tube was important for the arterial supply of the heart.

As far as we know, this is the first time any attempt has been made to use nylon tubes as substitution for the ordinary coronary flow in cases of experimental infarction. Smith and McIntyre,[10] however, recently published some results with Ivalon grafts from the left subclavian artery to the distal part of a ligated coronary artery, and they also found most of their grafts patent. The time during which tubes of artificial material remain open seems to be adequate to help the ischemic part of the myocardium over the critical period; i.e., the time required for the dog to develop functioning extra- and intracardiac anastomoses. This time has been calculated to be between 4 and 12 days.[11] Ultimately, however, the tubes get obstructed. If intramyocardial implantation of nylon tubes, or tubes of another inert material, should ever be attempted in man, it, therefore, should be combined with some other method of revascularization of the myocardium. Intrapericardial poudrage, cardiopneumopexy, or possibly ligation of the contralateral internal mammary artery could be considered as relevant procedures.

The tubes were implanted in the borderline between the ischemic area and the apparently healthy myocardium. This was done for two reasons. First, it proved to be the best place for technical reasons since sutures were likely to cut through the damaged tissue of the ischemic area. Second, it probably is of importance to supply the border zone since it was shown by Harris and Rojas[12] that the ectopic foci, which lead the heart into ventricular fibrillation following occlusion of a coronary artery, as a rule, are situated in this zone. Probably a slight increase of the arterial blood supply to this region will be most helpful to prevent early ventricular fibrillation.

SUMMARY

Artificial coronary thrombosis was created in dogs by the insertion of a magnesium-aluminum alloy wire in one of the major coronary arteries. In 16 dogs, no further treatment was undertaken; all of these animals died within 15 days after the wire implantation. In 15 dogs, electrocardiographic and/or clinical evidence of myocardial ischemia was found following the wire

implantation. These dogs were reoperated upon on the second to seventh day after the first operation. A nylon tube was inserted into the internal mammary artery and its other end buried in the border zone between the healthy and the ischemic myocardium. The dogs operated upon with this procedure survived a manifest myocardial infarction to 73 per cent (11 out of 15 animals). In 6 dogs, the same procedure was undertaken, but the implanted tube was closed. All these dogs died within 6 days after the second operation.

It is concluded that the intramyocardial implantation of a nylon tube carrying blood from the internal mammary artery, at least for some time, is effective in maintaining the necessary arterial blood supply to the ischemic area of the myocardium, and this procedure was contributory to the survival of the dog.

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